

## Appendix B Fluids Integrated Rack (FIR)

## Table of Contents

<b>B.1 Fluids Integrated Rack Overview</b>	<b>B-4</b>	<b>B.3 Utilization &amp; Operations</b>	<b>B-100</b>
B.1.1 Purpose of the FIR	B-4	B.3.1 Generic FIR Experiment Envelope	B-100
B.1.2 Concept of the FIR	B-6	B.3.1.1 Initial Principal Investigators for FIR	B-102
B.1.3 Operational Concept for FIR	B-6	B.3.1.2 Conceptual FIR Experiment Integration	B-104
<b>B.2 Fluid Integrated Rack System Design</b>	<b>B-10</b>	B.3.1.3 Granular Media	B-108
B.2.1 FIR Mission	B-10	B.3.1.4 Shear Rheology of Complex Fluids	B-110
B.2.2 FIR Overview	B-12	B.3.1.4 Shear Rheology of Complex Fluids (concluded)	B-112
B.2.3 Major Components	B-12	B.3.1.5 Multiphase Flow Boiling-Pool Boiling	B-114
B.2.3.1 Fluids Element	B-12	B.3.1.6 Contact Line Hydrodynamics	B-116
B.2.3.2 Core Element	B-12	B.3.2 FCF FIR On-orbit operations	B-118
B.2.3.3 Optics Bench Assembly	B-14	B.3.2.1 CDMS Operations Overview	B-120
B.2.3.4 FIR Electrical Power Distribution	B-26	B.3.2.2 PI Experiment Set-up Scenario	B-122
B.2.3.5 Overview of FIR Science Diagnostics	B-30	B.3.2.3 Operational Scenario	B-126
B.2.3.6 FIR Command & Data Management Subsystem	B-68	B.3.2.4 Crew Interaction	B-126
B.2.3.7 Fluids Science Avionics Package(FSAP)	B-76		
B.2.3.8 FIR Software	B-82		
B.2.3.9 Gas Interface System (GIS)	B-90		
B.2.3.10 Atmospheric Monitor Assembly	B-92		
B.2.4 FIR Metrics	B-94		

## Section B.1 Fluids Integrated Rack Overview

## B.1 Fluids Integrated Rack Overview

The FCF FIR is a modular, multi-user facility that accommodates science experiments on board the US Laboratory Module of the ISS where FIR is exposed to the microgravity environment. The FIR consists of two elements: **1)** a Fluids Element consisting of an Experiment Assembly comprised of science diagnostic and science specific packages for experiments; and **2)** a Core Element that provides the overall infrastructure necessary to support experimentation. The Core Element is comprised of subsystems that optimize, interface, and distribute ISS services. All science support hardware will be designed so as to provide an individual experiment with the best resource allocations allowable by the ISS.

### B.1.1 Purpose of the FIR

This document represents the current concept for the FIR and will be updated as necessary to reflect changes to the baseline concept. The FIR will support the NASA Microgravity Science and Applications Division (MSAD) and the NASA Human Exploration and Development of Space (HEDS) program objectives requiring sustained systematic research in fluid physics. This document is intended to facilitate communication between the various project groups and contains the necessary design data for team members to make technical recommendations and decisions during the early stages of the development process including:

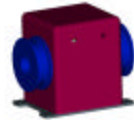
- **Technology, working principle(s), and physical form** of the FIR and its subsystems
- FIR and subsystem physical and performance **metrics**
- High-level functional **capabilities**

*The elements of the FCF FIR hardware concept are shown in the following figure.*

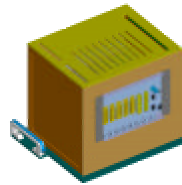
## Elements of the FIR Hardware Concept



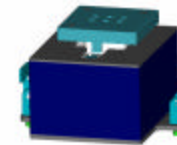
PI-Science Avionics



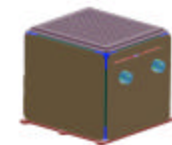
Laser Diodes



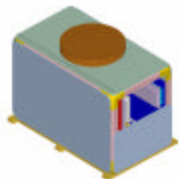
Science Avionics



Translation Stage



Dual White Light Source



Nd: YAG Laser

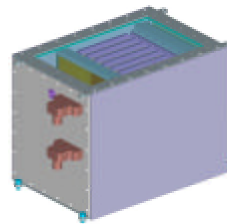
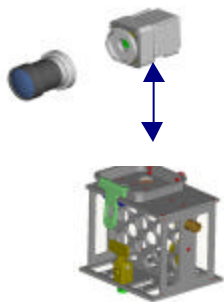


Image Processing



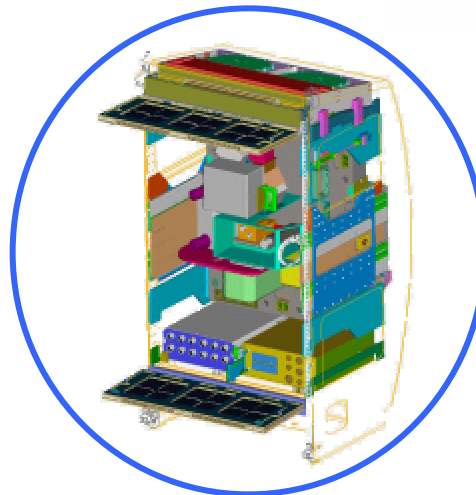
Atmospheric Monitor  
Assembly (concept)



Color Camera



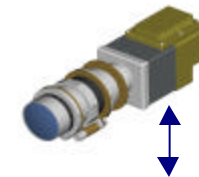
Collimators



*Fluids Integrated Rack*



High Frame Rate Camera  
(Concept)



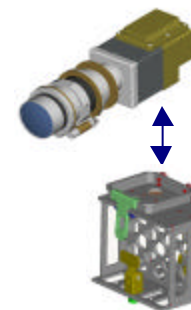
High-resolution Camera



White Light  
Fiber Weave



Gimbaled Mirror  
(Concept)



High-resolution Camera  
(High Magnification)

## B.1.2 Concept of the FIR

The concept of the FIR provides for a cost-effective approach and a long-lived answer to challenging requirements and significant constraints. The concept of the FIR utilizes :

- **ISS-provided common hardware** to minimize costs when the capabilities are compatible with the science mission
- **FCF-generated common hardware architecture** (including interface design) and subsystems, when possible, to minimize cost and increase redundancy
- Accessible **modular assembly** when possible to optimize access for flexible reconfiguration and maintenance while minimizing impact on crew time
- **Modular up-gradable hardware and software concepts** to permit evolutionary implementation of capabilities to meet selected requirements or improvements
- When possible, **FCF-generated diagnostic and measurement subsystems** that are chosen to optimize the long-term benefits to the science program
- **Designs and operational concepts** to perform the following functions:
  - **Maximize** accessibility and flexibility for users who implement experiment-specific capabilities while minimizing requirements for up- and down-mass
  - **Optimize** the implementation and the operation of safety-related systems and documentation

## B.1.3 Operational Concept for FIR

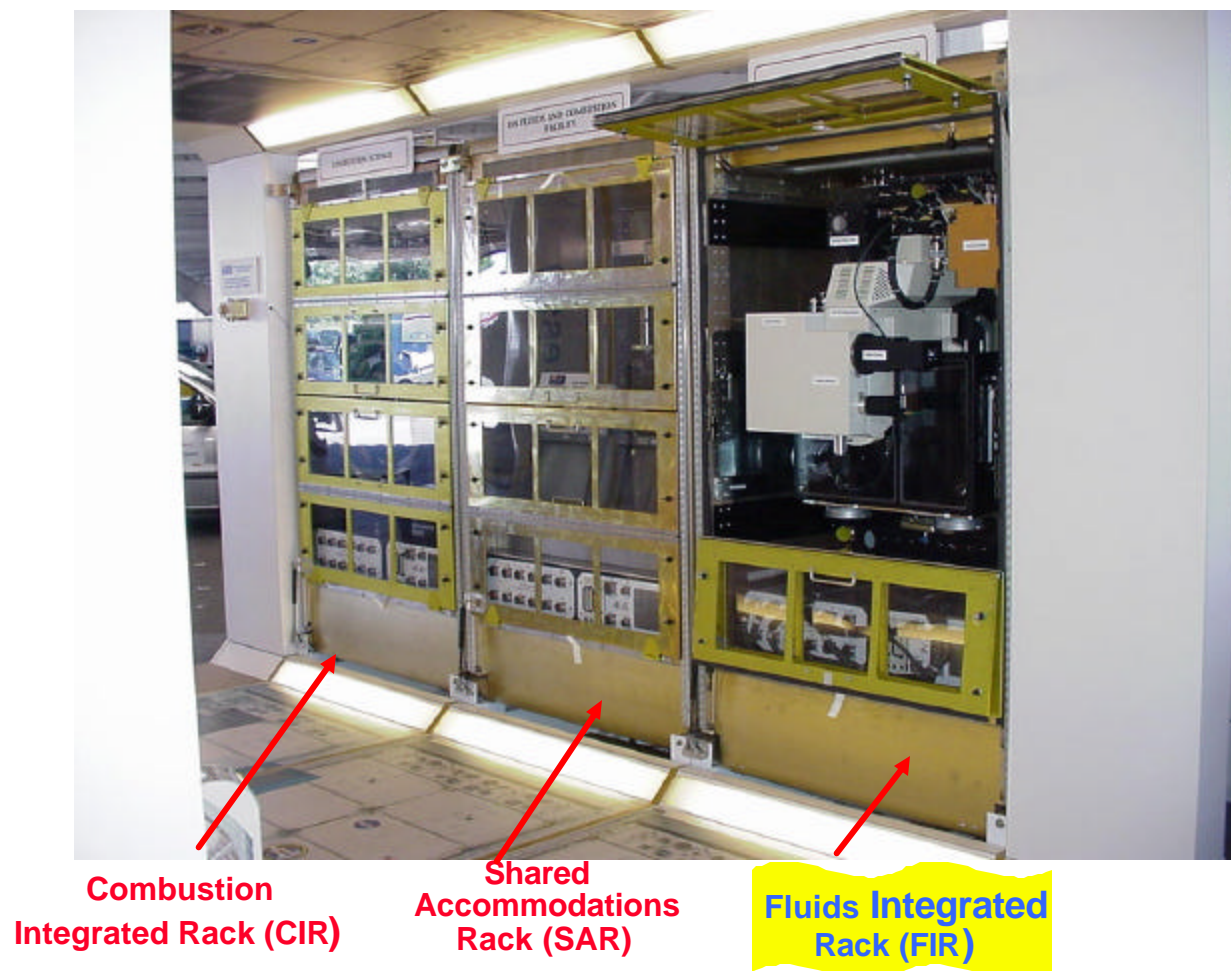
With the realization of long term and multiple access to the International Space Station (ISS) research environment as well as the ability to accommodate some on-orbit re-configurability of experiments, the Fluids Integrated Rack (FIR) concept is to be a modular multi-user facility. The FIR conceptual design presented within this document is defined to meet the requirements of the Fluids and Combustion Facilities (FCF) Science Requirements Envelope Document (SRED) while operating within the constraints of the ISS accommodations and available resources as currently understood.

The FIR involves the development and deployment of all on-orbit and ground equipment that is common to, or needed by, nearly all fluids physics research, but is not unique to specific Fluid Physics experiments. A FIR requirement will be to verify that each measurement capability is verifiable and representative of "state of the art". This requirement is what the facility has to offer to counter/entice the science community to shape experiments which are readily implemented rather than uniquely developed.

Since definition and design of the FIR architecture down to the subsystem/assembly/package level influences the scope of the operational on-orbit phase, the Fluids Design Team will consider the minimization of the consumption of external resources as one of the driving factors in the development approach. Therefore, mass, volume, the servicing and maintenance capability of the FIR based on modularity, the conceptual simplicity, and the functional and operational reliability are of eminent importance.

*The Fluids Integrated Rack (FIR) is shown in the US Lab the following figure.*

## ISS FCF in U.S. Lab Module Mockup



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## Section B.2 Fluids Integrated Rack System Design

## B.2 FIR System Design

### B.2.1 FIR Mission

Sustained fluid physics research in a microgravity environment is the principal focus of the FIR. Scientists use this microgravity environment to isolate and control gravity-related phenomena, and to investigate phenomena and processes that are normally masked by gravity effects and thus are difficult to study on Earth. The Space Shuttle, International Space Station and the Fluids and Combustion Facility serve as research platforms to pave the way for sustained human presence in space and provide for research with applications on Earth. The ISS differs from the shuttle science platform used in the past in that it is a long-duration laboratory that will provide unprecedented opportunities for science technology, and commercial investigations in the space environment.

The types of fluid physics science planned, but not limited, to be accommodated with the FCF FIR include thermocapillarity, fluid rheology, colloids, first and second order phase transitions, diffusive phenomena, electro hydrodynamics, multiphase flow, and granular media. Practical benefits of potential Fluids Science experiments conducted in the FIR include:

- **Environment**
  - Prediction of near and long term weather patterns
  - Dispersion of pollutants in the atmosphere and effects of climate change
- **Industry**
  - Power generation
  - Aeronautics and aerospace
  - Improved commercial processes/competitiveness in a wide range on industries

- **Advanced Technologies**

- Support future national decisions regarding missions beyond Earth orbit
- Expand scientific knowledge
- New propulsion technologies
- Enable commercial development of space
- Greater success in applying the results of other experiments conducted on ISS to benefit the public

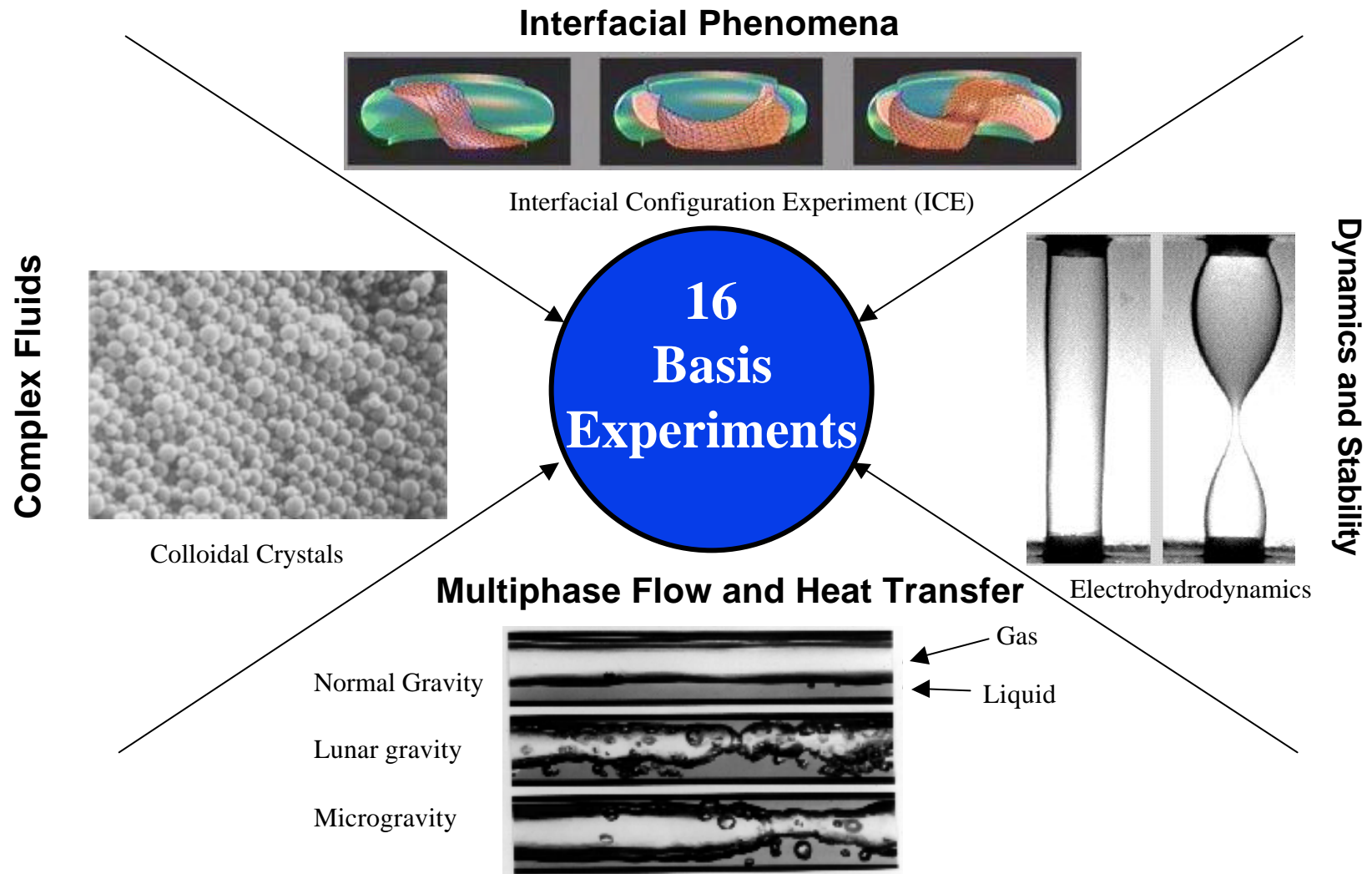
Fluids physics processes are ubiquitous. The behavior of fluids is paramount to many phenomena governing materials science, biotechnology and combustion science. The human body is also predominantly fluids; thus, creating new drugs and treating disease frequently depends on fluids physics. Numerous high-value commercial processes, such as petroleum production and semiconductor production, rely on fluid physics. In addition, many other experiments conducted on ISS require a knowledge of microgravity fluid physics to interpret the results.

- **Biological Systems**

- Fluid flow in the human body and other living systems
- Biotechnological systems
- Advances in public medicine and treatment of disease

*The hardware overview of the Fluids Integrated Rack (FIR) is shown in the following figure.*

## Mission: Fluids Physics Research



## B.2.2 FIR Overview

The FCF FIR is a modular, multi-user facility that accommodates science experiments on board the US Laboratory Module of the ISS where FIR is exposed to the microgravity environment. The FIR consists of two elements: **1)** a Fluids Element consisting of an Experiment Assembly comprised of science diagnostic and science specific packages for experiments; and **2)** a Core Element that provides the overall infrastructure necessary to support experimentation. The Core Element is comprised of subsystems that optimize, interface, and distribute ISS services. All science support hardware will be designed so as to provide an individual experiment with the best resource allocations allowable by the ISS.

## B.2.3 Major Components

### B.2.3.1 Fluids Element

The FIR primary structure is the Optics Bench Assembly. Mounted to the Optics Bench Assembly will be various Science Diagnostic Packages and Science Specific Packages to accomplish the facilities mission.

#### Science Diagnostic Packages

Science Diagnostic Packages provide the standard rack hardware that is responsible for science-specific mounting, precision alignment, data acquisition and control, optical systems, and interface support that includes science avionics, power conversion, imaging and illumination.

The following packages comprise the Fluids Diagnostic Subsystem:

- **Optics Bench Assembly**
- **Imaging Packages:**
  - Camera Assembly
  - Lens Assembly

- **Illumination Packages:**
  - White Light Assembly
  - Fiber Weave Panel
  - Fiber Bundle
- **Lasers:**
  - Nd: YAG Laser Assembly
  - Laser Diode Assembly
- **Optical Packages:**
  - Collimator Assembly
  - Translation Stage Assembly
  - Scanning Mirror Assembly

### B.2.3.2 Core Element

The FIR is supported by the following core science support subsystems:

- **Command and Data Management**
  - Command, data and image processing will be supported via a rack Input/Output Processor
  - Software utilizes embedded internet technology that is platform independent
- **Electrical Power Distribution**
  - Power distribution will be performed via an Electrical Power Control Unit
- **Environmental Control**
  - Air/Water heat exchanger utilizing hybrid water air heat rejection system
  - Smoke Detection/Fire Suppression
  - GN<sub>2</sub>, Vacuum Vent, and Vacuum Resource interfaces
- **Structural**
  - Rack stiffening and strengthening
  - Rack closure doors
- **Active Rack Isolation**

*The FIR science capabilities are shown in the following figure.*

## Fluids Science Capabilities Overview

### ***FIR Features:***

- Easy access via fold down bench
- Diagnostics easily reconfigured, replaced/interchanged on optics plate
- Accommodates many experiment configurations and disciplines

### **Image Processing Packages:**

- High-speed Cameras - 1024×1024 12-bit pixels up to 110 fps
- High-resolution Microscopic Camera -8x magnification for 2.6 mm × 2.6 mm field, 4 micrometer resolution
- Color Camera: at least 484×768 pixels
- Ultra-high Frame-rate Camera (>500 fps)-Available after SAR Launch
- Data collection at 40 MB/sec

### **Environmental Control:**

Fans (2) and Radiator(s)

- 500 W of cooling (air/water) available to PI Unique H/W
- 16 C inlet - 48 C outlet water
- Rack Structural Augmentation

### **Rack:**

- Baseline—4
- Standard ARIS
- FCF Slide Package
- Pin Assembly

### **Optics Plate:**

- Width: 89.5 cm (35.25 in.)
- Length: 119.4 cm (47 in.)
- Depth: 12.7 cm (5 in.)
- Wiring internal and external to plate

### **Optical Components:**

- Lenses
- Collimators
- Fiber optic cables
- Gimbaled Mirror

### **Avionics:**

- ISS Command and Data Interface
- Supervisory Control and Data Acquisition for Experiments
- CAN Interfaces to Test Section and IOP
- ADC

### **Illumination and Laser Packages:**

- White Light via fiber Weave
- Laser Diodes
- Nd: YAG

### **Door:**

- Structural augmentation
- Thermal/Frangible laser light containment
- 20 inches from front of optics plate to rack door

### **Electrical Power:**

Electrical Power and Control Unit (EPCU)

- 4 PU Drawer
- Cold Plate
- Power Regulated to 28 Vdc
- 48 Switched, 28 Vdc Channels
- Each Channel limited to 4 A

### **Software:**

- Embedded Internet Technology
- Platform Independent
- Allows for PI interaction at home site

### B.2.3.3 Optics Bench Assembly

The Optics Bench Assembly allows a scientist to have a familiar laboratory-style “optics bench” interface with the facility on which an experiment will be configured. Standardized interfaces will be utilized to permit flexibility in equipment placement and replacement/upgrades, including standardized mounting and electrical connections. Acceleration measurement will be provided by a SAMS Free Flyer Head placed near the PI-hardware mounting interface.

The Optics Bench Assembly provides the structural support, mounting and resource interface locations for all FEA hardware. The Optics Bench Assembly consists of two regions. The front of the optics bench provides precision alignment and stable thermal environment and is dedicated primarily to science-specific Experiment Packages (EPs) integration. The back is a **mounting plate** that is dedicated to several multi-function, non-intrusive optical diagnostics packages, and to science avionics support packages. The experiment interface is provided via a umbilical interface for optimal flexibility.

The Optics Bench Assembly has the capability to remove and replace different PI-specific EPs. The EP interface connections are provided. Connections will be made after the EP is installed during a typical ISS increment.

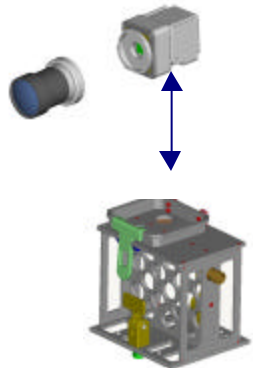
The PI-specific EP may consist of a single self-contained unit and/or several separate components. The PI-specific assembly will typically be a unique design, but it may re-use hardware/designs and the container from previous experiments. The EP will consist of the fluids test cell and any support equipment such as injection devices, motors, and so on.

**Standard interfaces** include power, control, sensor, water for thermal control, vacuum, vent, and  $\text{GN}_2$ . **Electrical harnessing** includes power, control, and data. Where appropriate, the FIR will build upon subsystem hardware developed for the Combustion Integrated Rack (CIR) for commonality and development cost savings.

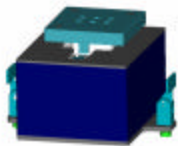
The **Fluids Experiment Assembly (FEA)** consists of an enclosed volume with access provided via a door on the front of the rack. The FIR will provide standardized mounting and interfaces to support the PI hardware.

*FIR Science Diagnostics available to a PI is shown in the following figure.*

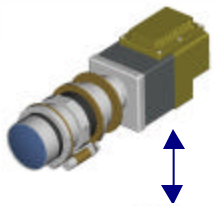
## FIR Science Diagnostics Available to an Experimenter



Color Camera

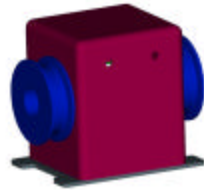


Translation Stage

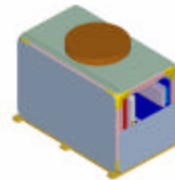


High-Resolution Camera

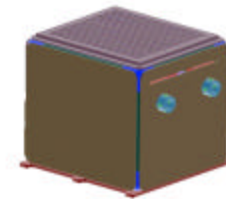
F4007, Rev. 3



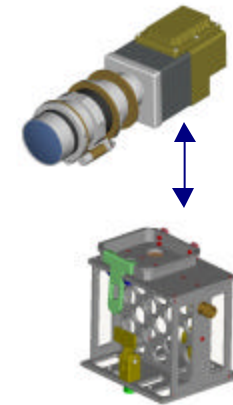
Laser Diodes



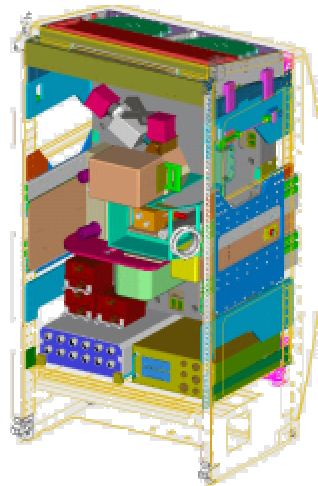
Nd: YAG Laser



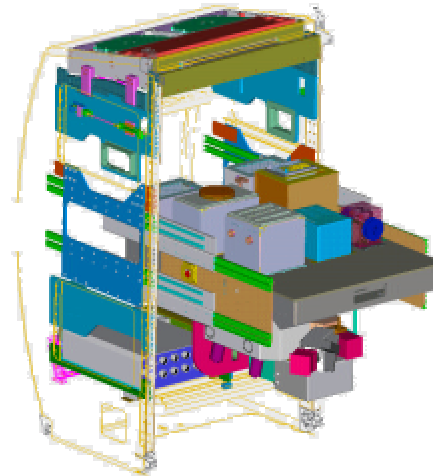
White Light



High-resolution Camera  
(High Magnification)



*Operational Orientation*



*Diagnostic Changeout Orientation*



Collimators



High Frame Rate Camera  
(Concept)

B-15



Gimbaled Mirror  
(Concept)



White Light  
Fiber Weave

FCF Baseline System Description

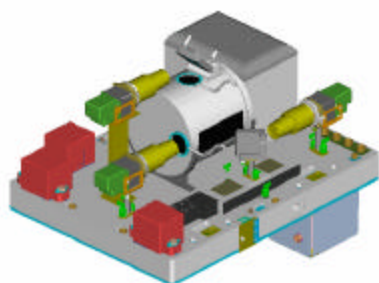
### B.2.3.3.1 Performance

The Optics Bench Assembly provides the structural support, mounting and resource interface locations for all FEA hardware. The back is a mounting plate that is dedicated to the following multi-function, non-intrusive optical diagnostics packages, and to the science avionics support package:

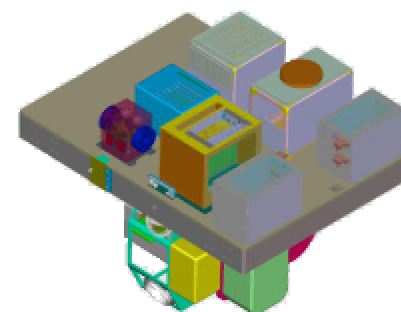
- **Volume** - The optics bench assembly provides nearly 1 square meter of surface area on which experiment hardware may be configured. A maximum of approximately 492 liters of science specific volume can be accommodated with the front of the optics plate bare ( i.e. no FIR provided diagnostics).
- **Standardized Interfaces** - Standardized interfaces will be provided for electrical power, video and digital data acquisition, motor control, vacuum ventline, GN<sub>2</sub>, thermal control, and light detection circuitry interfaces.
- **Mounting** - Precision mounting/locking of PI-specific hardware/test cells and components will allow critical imaging applications such as interferometry and micro-imaging to be performed. Alignment of components will be performed via on-board processor or teleoperative control of component translation stages.
- **Containment** - During experiment operations, the FEA will provide the Optics Bench Assembly protection against the contamination of sensitive optics by U.S. Lab Module air and light, as well as serve as a barrier against escape of internal laser radiation and frangibles.
- **Thermal Control** - The optical-bench and mounting surfaces of the Optics Bench Assembly will be cooled via forced air circulation to the ISS moderate temperature water loop. Water loop access will additionally be available for the PI-specific equipment.. Air flow on the front side of the plate will nominally be allowed for thermal control and smoke detection. Provisions will also be made for power and control of PI-provided thermoelectric coolers where necessary to meet stringent thermal control requirements.

*An overview of the FIR Optics Bench Assembly concept showing both the science-specific and science-support sides of the Optics Bench Assembly is shown in the following figure.*

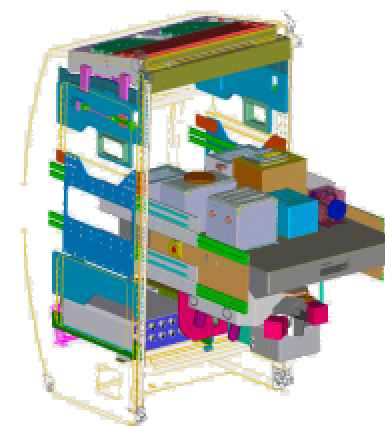
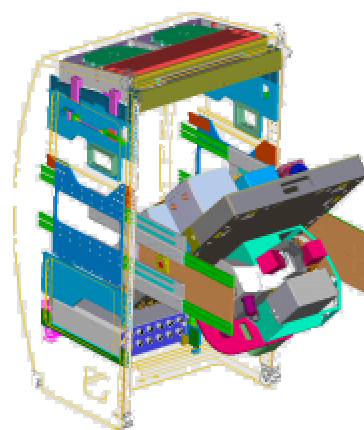
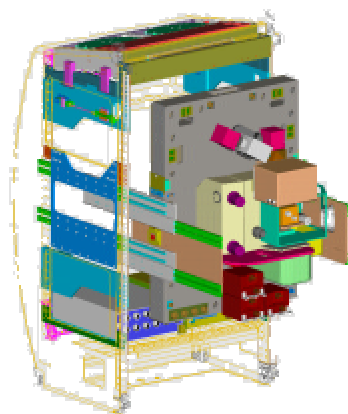
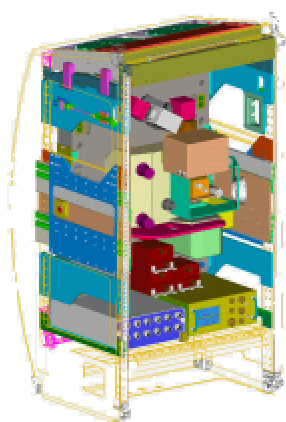
## FIR Optics Bench Assembly Overview



**Optics Bench Front**  
*Science*



**Optics Bench Rear**  
*Science Support*



*FIR Optics Bench: Operational to Diagnostic Reconfiguration Orientations*

### B.2.3.3.2 Optics Plate Description

The FIR optics plate is a rotating platform which serves as the mounting base for the system optics, samples, experiment-specific packages, and electronics. The optics plate will have components mounted on both the front and the back surfaces. To the back surface will be mounted components that generate the most heat (electronics, lasers, and computers). The front surface will be used to mount the experiment package, camera packages, and light delivery optics.

#### Mechanical Definition

FIR shall provide a surface which allows for the positioning of optical systems (cameras, light sources, and associated electronics), and procedures to reproducibly position and align the hardware and other experimental components located within the dedicated fluid physics volume. The relative positions of components shall be reproducible and knowable with the accuracy and precision required by the majority of basis experiments. The optics plate criteria is as follows:

- **Overall dimensions** – 89.5 cm × 119.4 cm (35.25 in. × 47 in.)
- **Mounting dimensions:**

Front: 70 cm × 100 cm (27.6 in. × 39.4 in.)

Rear: 84.5 cm × 116.8 cm (33.25 in. × 46 in.)

- **Top surface material** - Aluminum alloy with an optically non-reflective surface treatment.
- **Top mounting options** – T-type rail design - 50 mm on center, the design is similar to milling machine table surface. This design will provide a slide mount internal to the optical table. M6 mounting holes will be provided at predetermined locations. The colored grid that is spaced every 25 mm (1 in.) is to be used as an index mark, and indentation points will be at the grid/slide intersection. Map-type identification labels will be on the table surface.

- Provide **electrical**, **data**, and **environmental interfaces** to support the facility and PI-specific hardware.

#### Optical/Structural Definition

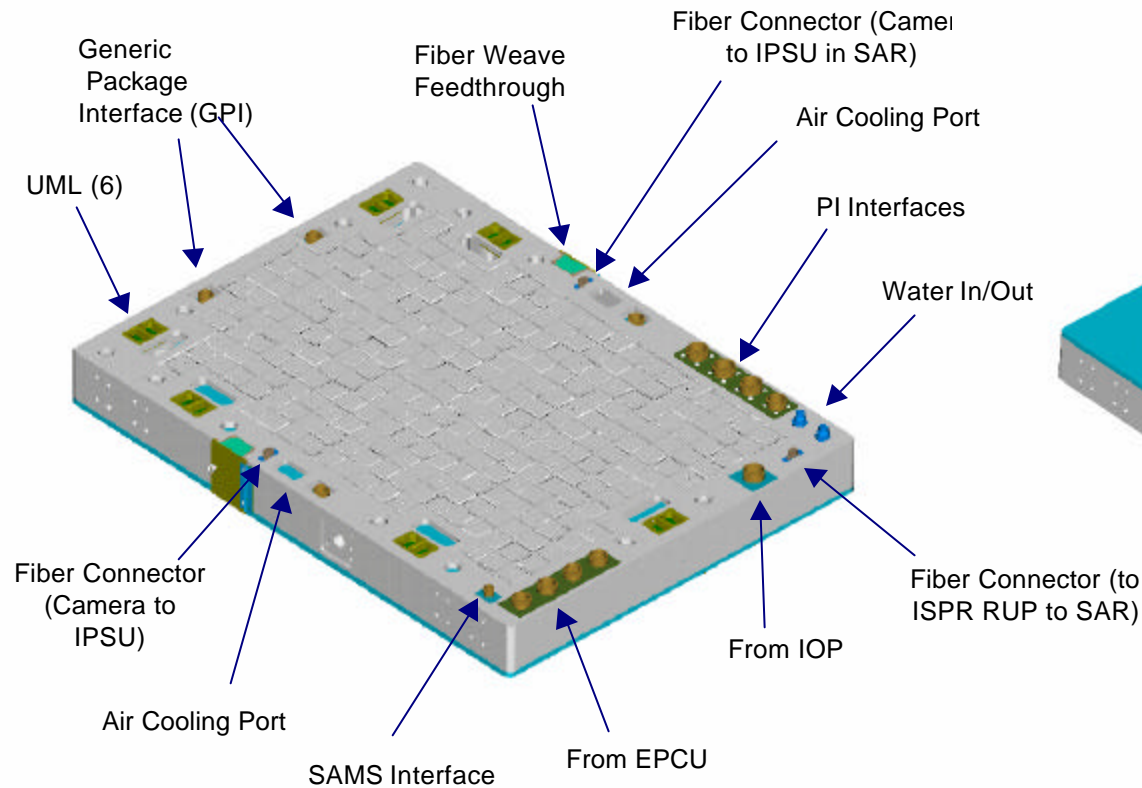
The optical requirements define the features and performance required to avoid degradation of optical measurements. Some of the following requirements also define structural requirements:

- Top flatness - p-p variation of < 0.5 mm
- Stiffness - TBD, Compliance < 1 μm / N
- First Harmonics > 100 Hz (bending and torsional modes). Must dampen normal modes of vibration.
- Top surface color Matte black (to minimize reflections)
- Isolate front plate from back plate

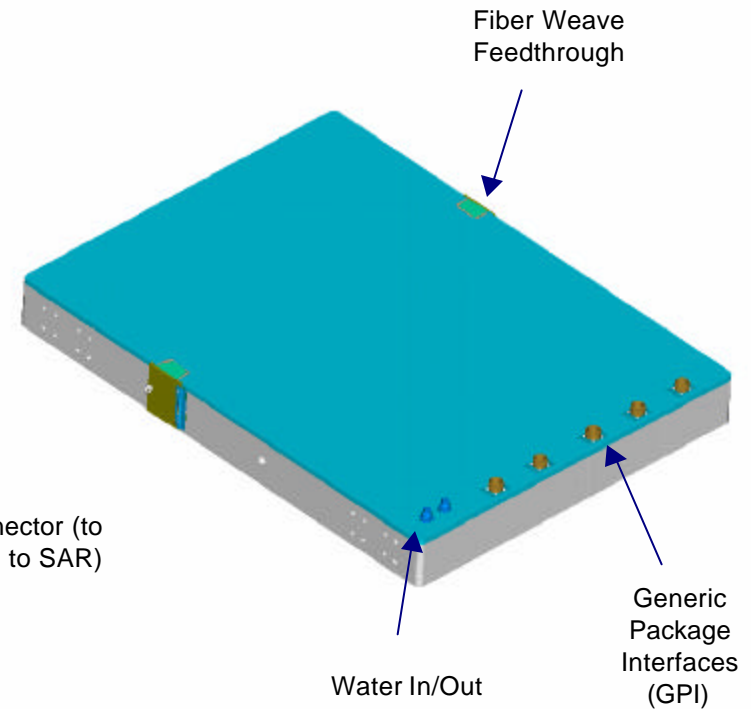
It is suggested that positions be measurable in a standard 6 degrees of freedom coordinate system (for example, x, y, z, θ, and so on). It is expected that any item installed in the facility by the crew on the optical bench will be *coarse-aligned to specific reference points, and that a mechanism for coarse-alignments (made by the crew) will be provided by the facility*. It is suggested that coarse alignment position coordinates (relative to a standard reference point) be reproducible and knowable with an accuracy of 2 mm (0.08 in.) and 2 degrees if the PI experiment and hardware both require and support such accuracy.

*The science interfaces available to an experiment on the Optics Bench Assembly are shown in the following figure.*

## FIR Optics Bench Assembly Science Interfaces



Optics Bench Front  
(Science)



Optics Bench Rear  
(Science Support)

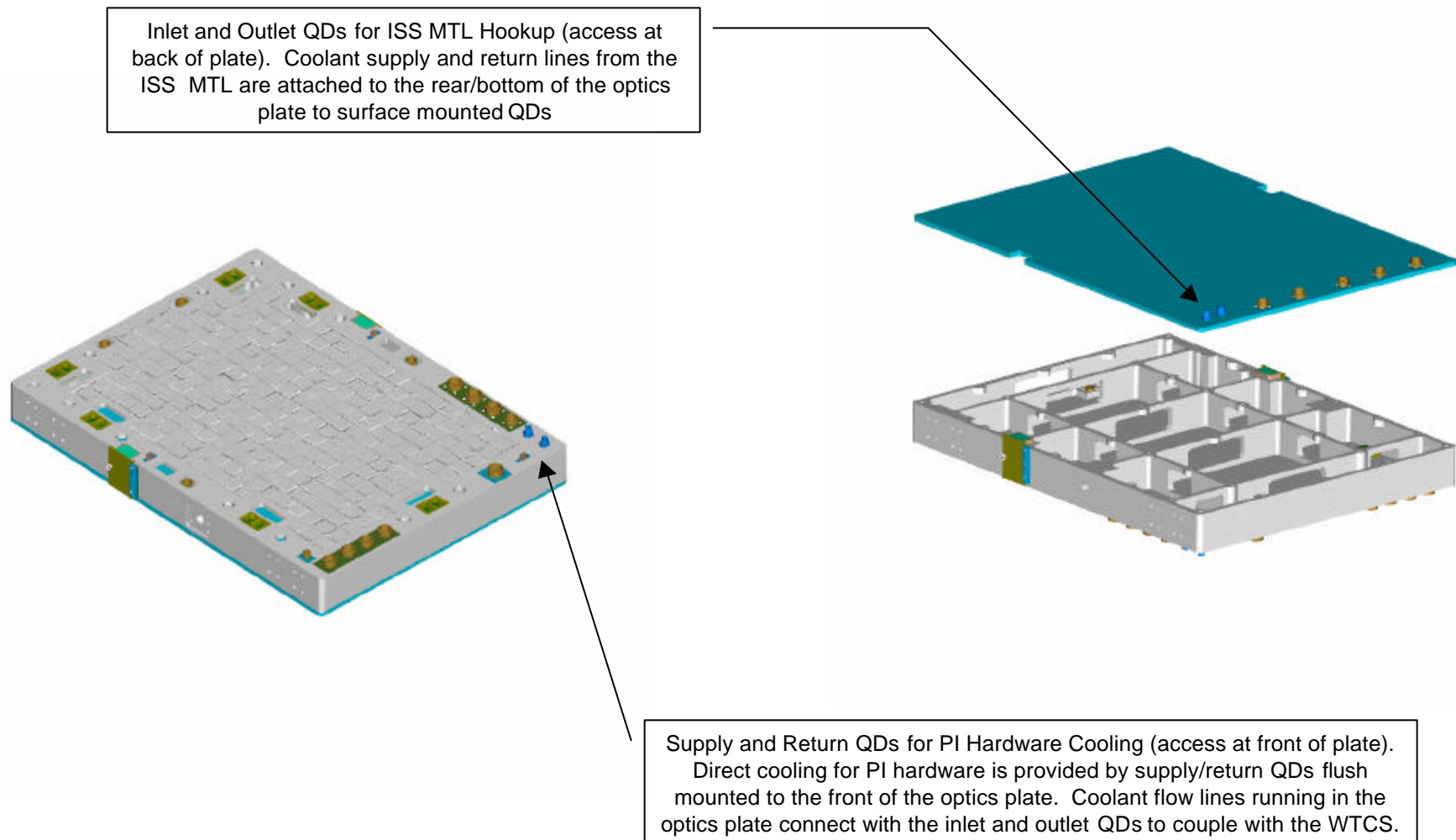
### **FIR Optics Plate Water Cooling Interfaces**

The Optics Plate Interface (OPI) is the site for coolant supply and return lines to be attached to the rest of the WTCS. From the OPI, coolant flow is routed to direct PI cooling lines.

The OPI consists of two flush mounted male QDs located at the rear, left, bottom of the optics plate. Inside the optics plate, the supply flow line runs to a QD on the front of the optics plate. Here, PI hardware may hook up to the WTCS for direct cooling. Return lines for the PI hardware cooling meet at the OPI and a flexible return line combines with the EPCU exit flow and exits the rack via the RUP.

*The optics plate interfaces are shown in the following figure.*

## FIR Optics Plate Water Cooling Interfaces



### B.2.3.3.3 Optics Plate Configuration Options

#### Mounting Locations

The design of the optics plate will provide for infinite mounting positions. The optics plate will have 8 (4 front, 4 back) generic package interface (GPI) connectors for diagnostics packages. Any FIR diagnostics package can be connected to any GPI without the need for additional cable reconfiguration by the astronaut. Additional interfaces on the front of the optics bench are provided for PI-specific connections to the Fluids Science Avionics Package (FSAP).

#### Mechanical Connections

An off-set cam lock-type lever will secure a spring loaded ball bearing slider plate to the optics bench. The various optical packages will either have the slider plate designed into the housing or will be attached to the slider plate with an L-type bracket of some sort. The back of the optics plate will accommodate this type of mounting to allow for the stowage of the FIR provided components. The use of this design allows for the crew to attach and position components without the use of any hand tools.

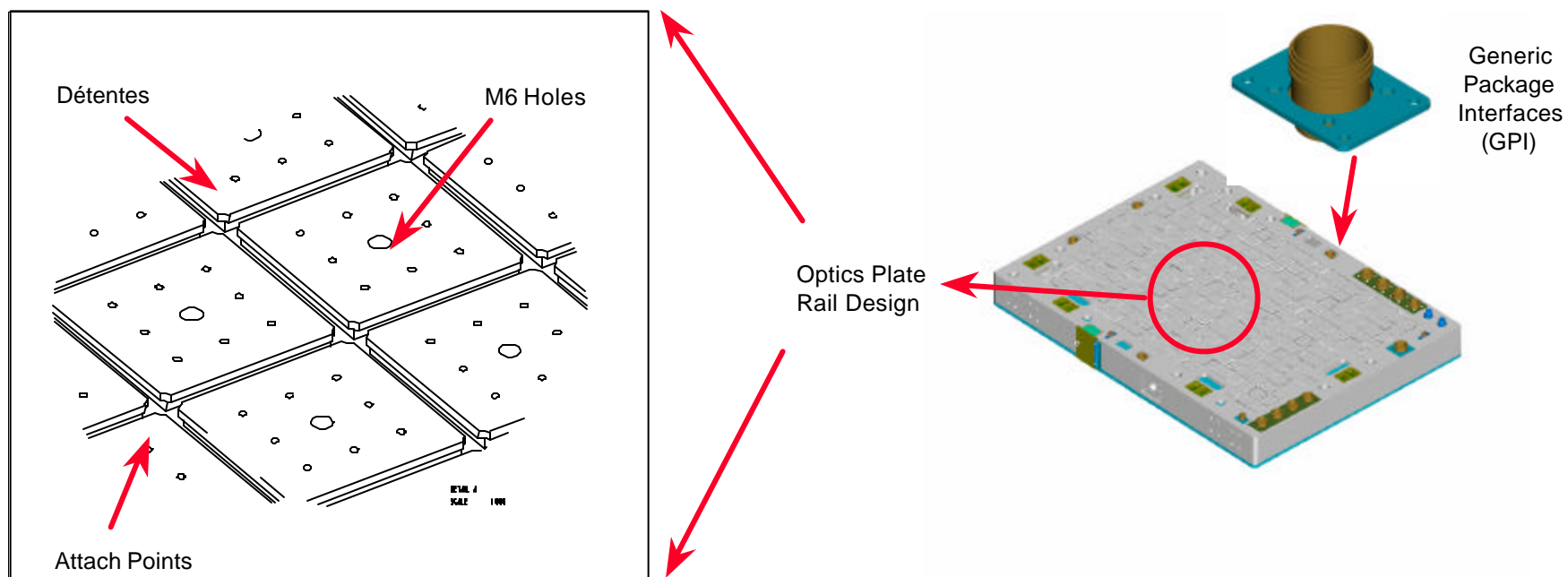
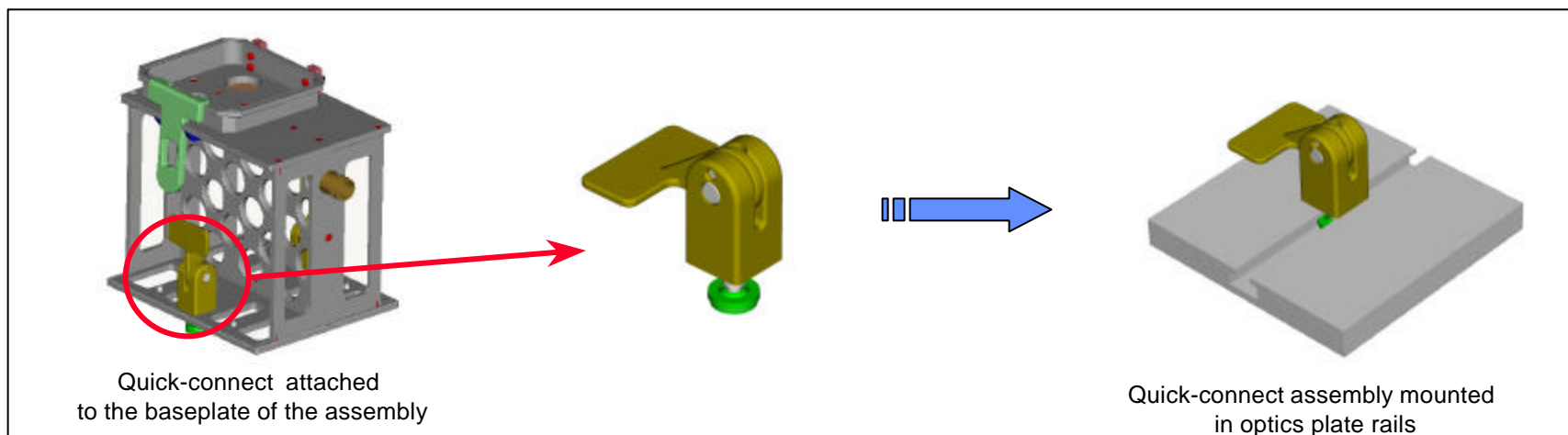
At the center of several of the optical bench's squares are standard M6 holes. These holes will allow for the attachment of large PI-specific hardware not requiring accurate positioning at the optics plate.

#### Electrical Connections

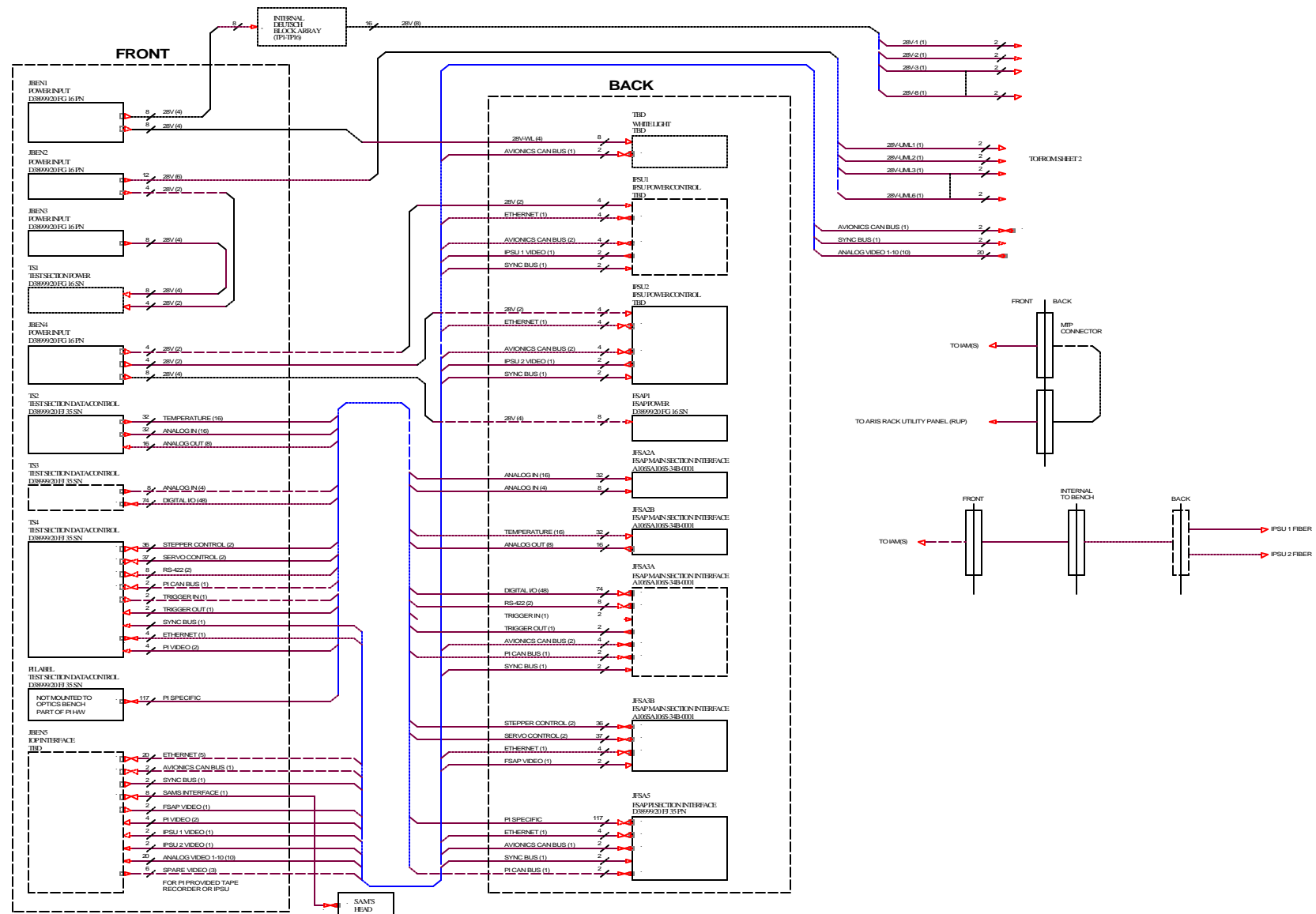
The optics plate has 14 electrical connectors (6 UMLs and 8 GPIs) for connection of diagnostics packages. These connectors are TBD-type (part # TBD) with electrical and fiber contacts. The connectors are arranged around the perimeter of the plate.

*The quick-connect assembly concept and the rail design of the optics plate is shown in the following figures as well as the optics plate electrical block diagrams.*

## FIR Optics Bench Quick-Connect Concept



## FIR Optics Bench Electrical Block Diagram (1 of 2)





### B.2.3.4 FIR Electrical Power Distribution

#### FIR Power Components

The FCF FIR Electrical Power Subsystem (EPS) consists of an Electrical Power Control Unit (EPCU), cables from ISS to the EPCU, harnesses from the EPCU to PI/facility loads, PI/facility load converters, a 1553B interface between the EPCU and IOP, a Rack Maintainance Switch Assembly (RMSA), an EPCU Shutoff Switch Assembly (ESSA), and Rack Door Limit Switch..

#### FIR Power Distribution

120 VDC is applied to the input of the EPCU. The EPCU provides a quantity of six 120 VDC, 4 Amp and forty-eight 28 VDC, 4 Amp output channels. One 120 VDC channel is routed to the FDSS and ARIS each. Three 120 VDC channels are routed to the PI 120 VDC power connector on the front left side of the rack. Of the forty-eight +28VDC channels, three are routed to the IOP, four are routed to the ECS, and twenty-eight are routed to the optics bench for avionics, diagnostic, and PI use. Of the 28 channels to the optics bench, six are available for PI use. The drawings on the following pages show the power distribution for the FIR.

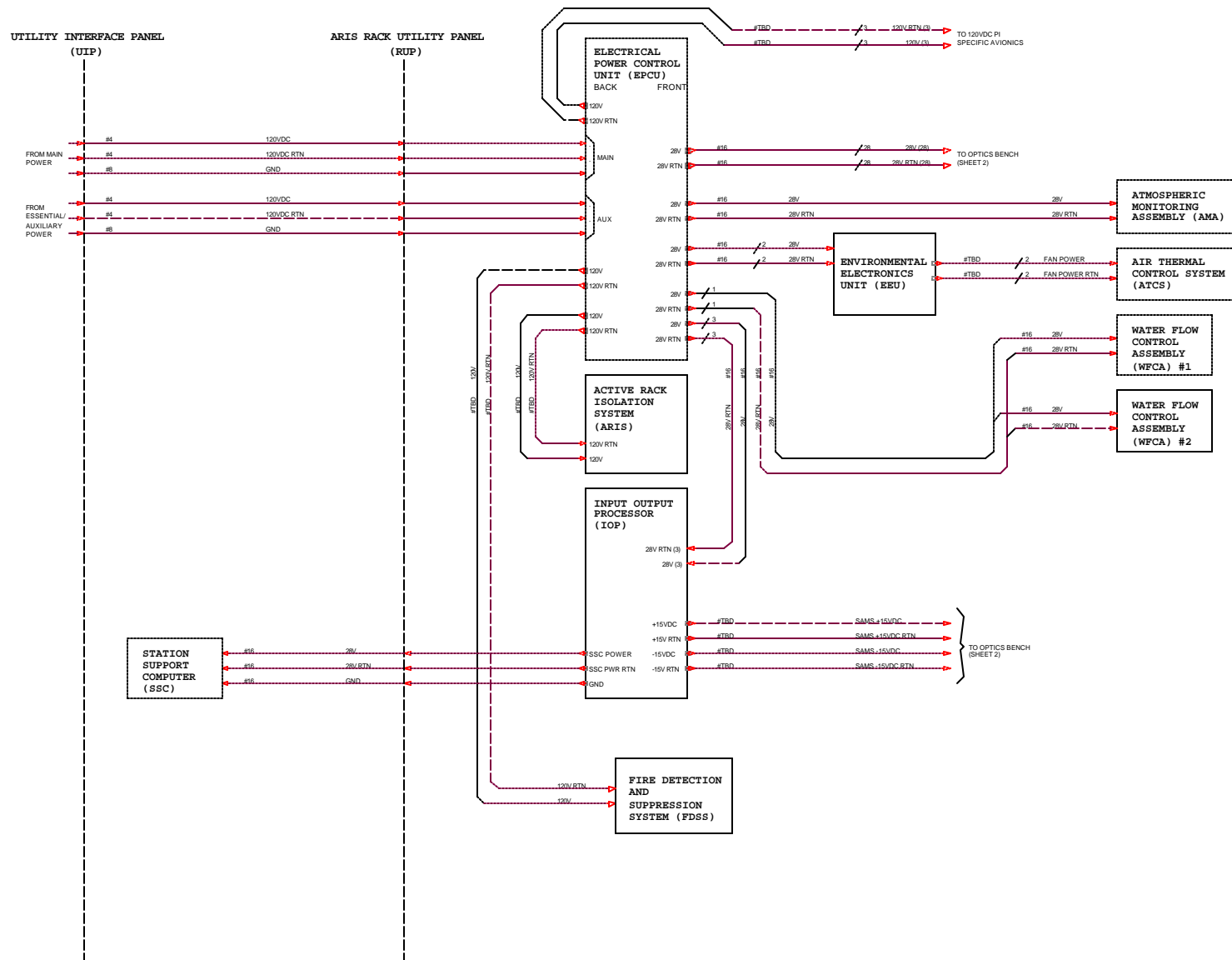
#### Bonding and Grounding

Grounding of each package in the FIR is accomplished utilizing a ground wire electrically connecting the package enclosure to rack structure and/or an electrical bond through the package faying surface to the rack structure. Each package not on the optics bench is electrically bonded to the rack structure via its faying surface and mounting to the rack. The optics bench is electrically bonded to the rack structure via a bond strap connected to a rack post. Packages on the optics bench are electrically bonded to the optics bench via the contact between their faying surfaces and the surface of the optics bench, or by the contact of their faying surfaces to other package surfaces, which are bonded to the optics bench. In addition, all packages on the optics bench are grounded utilizing a ground wire. Ground wire contacts in the input power connector of each package are electrically connected to the package structure. The input power connection to the optics bench contains a ground wire, that is electrically connected to the bench.

The ground fault current path is then from the package enclosure, through the ground wire, to the optics bench, through the bond strap, to the rack post, to the EPCU. Each ground fault current path is capable of handling the maximum fault current that is possible.

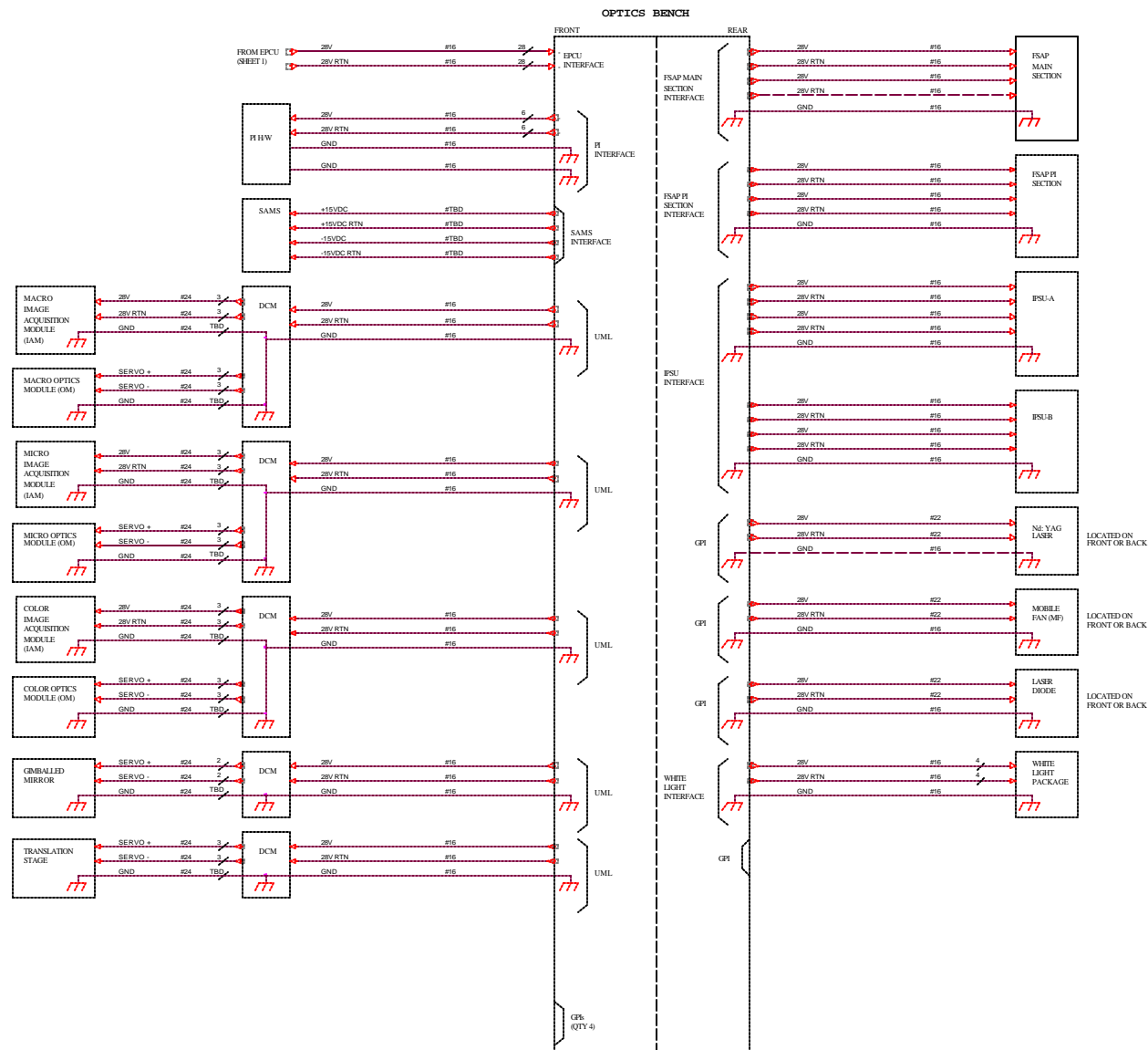
*The following figures illustrate the FIR power distribution of the FIR as well as the optics bench.*

## Fluids Integrated Rack Power Distribution Block Diagram (1 of 2)



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## Fluids Integrated Rack Power Distribution Block Diagram (2 of 2)



- NOTES:
1. SECONDARY POWER GROUNDS OF EACH PACKAGE TIED TO STRUCTURE AT ONE LOCATION (SINGLE POINT GROUND).
  2. OPTICS BENCH GROUNDED TO RACK STRUCTURE VIA BOND STRAP.

## **B.2.3.5 Overview of FIR Science Diagnostics**

### **B.2.3.5.1 Imaging Packages**

Digital cameras will be provided as the standard means of image acquisition in the FIR towards meeting requirements for high-resolution. The cameras will allow for the varying of image acquisition rates and times. Digital image storage also permits unlimited re-use of the recording medium, as opposed to image storage using videotape or film. The FIR will also be capable of supporting analog cameras through digitization of the analog data. The Imaging Packages also include lenses and mirrors outside the PI hardware package to assist in acquiring images of the test cell.

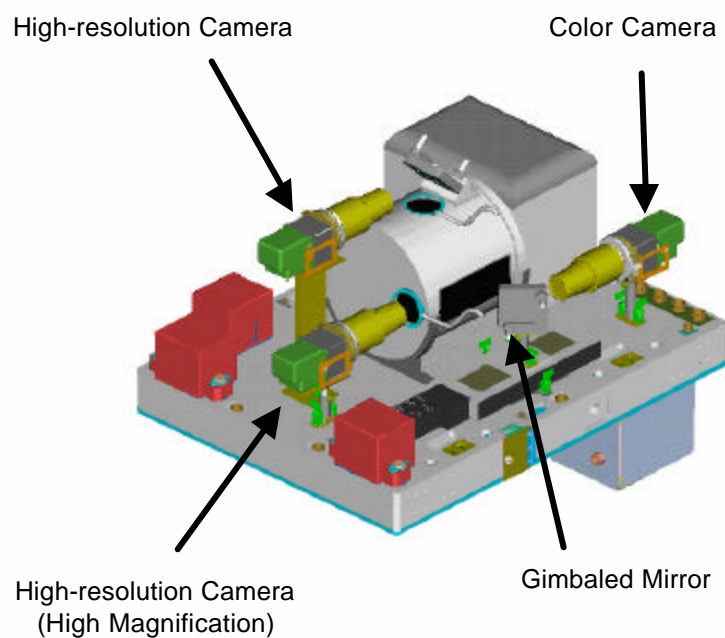
The common diagnostic architecture will allow camera and lens packages to be interchangeable. PI-specific cameras may be accommodated if their nonstandard cables are supplied as part of the PI-provided hardware, and if the cameras are compatible with the provided image acquisition boards. Future upgrades would allow additional cameras and acquisition boards.

### **B.2.3.5.2 Illumination Packages**

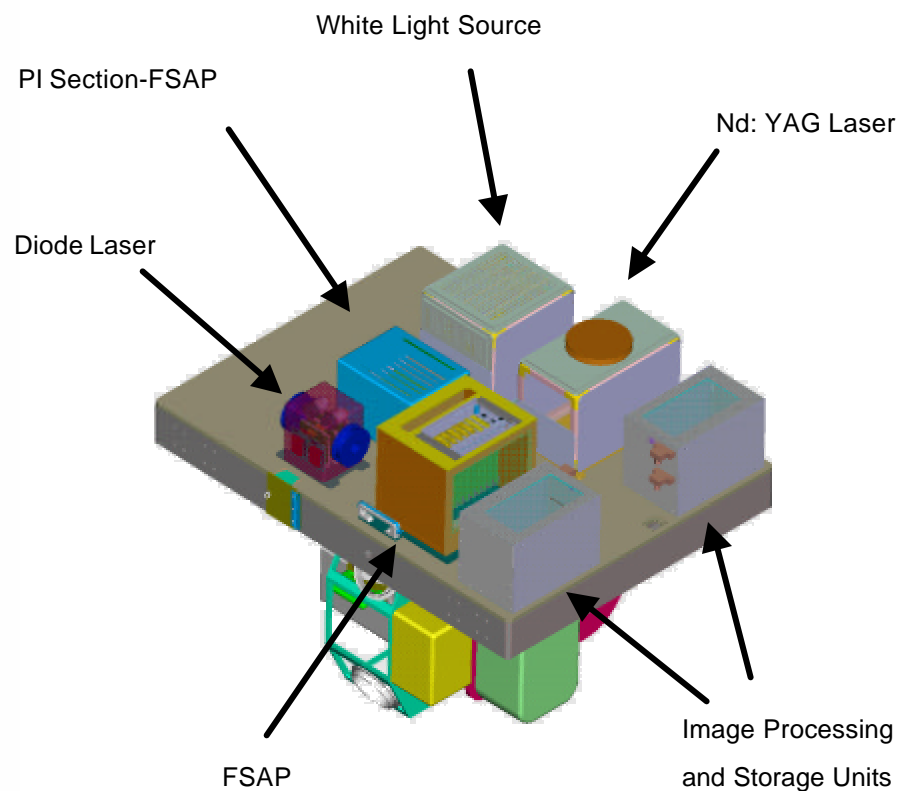
The purpose of providing light sources in the FIR is to enable the cameras to obtain meaningful images of scientific phenomena, and to enable the execution of specific diagnostic techniques, such as light scattering. The facility will provide white light sources which will allow acquiring color images as well as eliminating “ringing” in the image caused by light that is highly coherent. In addition to the white light sources, the facility will provide 3 lasers.

*An overview of the FIR Diagnostic Packages on the optics plate is shown in the following figure.*

## FIR Science Diagnostic Packages



***Optics Plate Front - Science***



***Optics Plate Rear - Science Support***

### **B.2.3.5.3      Technical Description of the Imaging Packages**

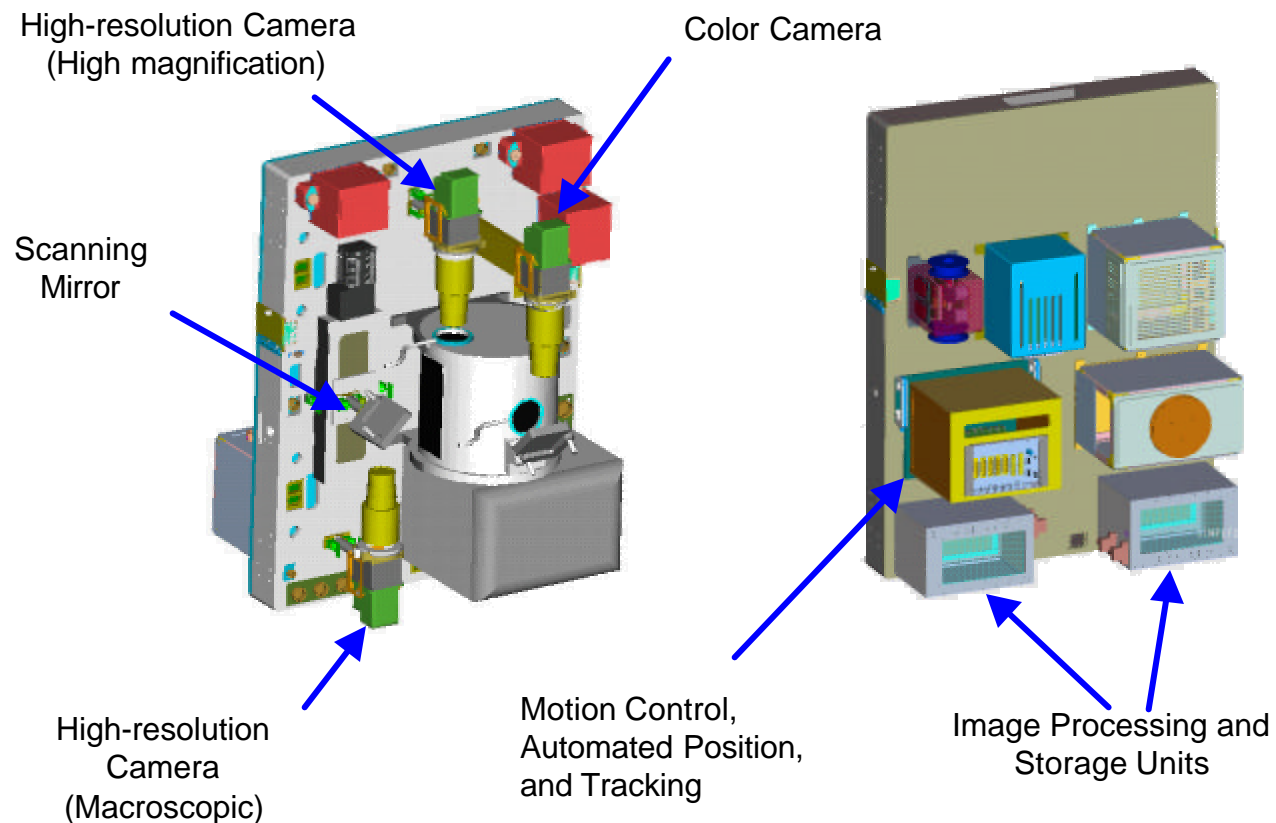
Utilizing a suite of cameras, lenses, configurable mirrors, and ancillary support equipment, the Imaging Packages provide a flexible and feature-rich environment for acquiring high-quality digital video images. Two digital cameras and one analog color camera have been identified as standard initial FIR resources.

*The imaging packages that are available to FIR experiments initially on-orbit is shown in the following figure.*

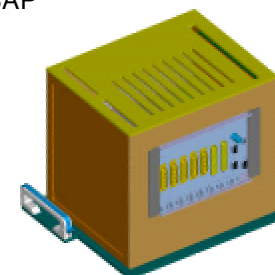
## FIR Imaging Package Overview

### Imaging Packages:

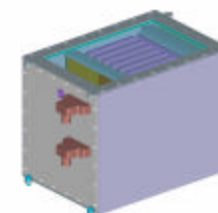
- High-speed Cameras -  $1024 \times 1024$  12-bit pixels up to 110 fps
- High-resolution, Microscopic Camera -8x magnification for  $1 \text{ mm} \times 1 \text{ mm}$  field, 3 micrometer resolution
- Color Camera: at least  $484 \times 768$  pixels
- Ultra-high, Frame-rate (UHFR) Camera (>500 fps) -Available after SAR Launch
- Data collection at 40 MB/sec



FSAP



IPSU



### B.2.3.5.3.1 Performance Requirements

The functions that are available with standard equipment include the following items:

- Automated Position and Tracking
- Automated Focus/Zoom
- On-orbit Reconfiguration/Changeout
- Video Data Collection
- Image Processing and Storage

Gimbal-mounted mirrors and motorized lenses will provide the required flexibility for different optical paths, orthogonal viewing, and orbit remote alignment. Optical component mounting is designed for easy astronaut changeout and reconfiguration.

#### B.2.3.5.3.1.1 High-Resolution Black and White Cameras

**Two monochromatic** (black and white) **cameras** will provide high-resolution images. The Charged Coupled Device (CCD) cameras will have  $1024 \times 1024$  12-bit pixels to provide high-resolution images at 30 frames per second (fps). These cameras also accommodate lower frame rates. The lower frame rates which may be selected are 7.5, 15, and 30 fps.

**Binning capability** enables the readout of  $512 \times 512$  images for experiments which do not require the full resolution of the sensor. The following **exposure times** are available via an electronic shutter: 1/60, 1/125, 1/250, 1/500, and 1/1000 of a second, and integrations of up to one (1) second may be accommodated by this sensor. In addition, these monochromatic camera sensors will contain antiblooming circuitry.

### Mounting

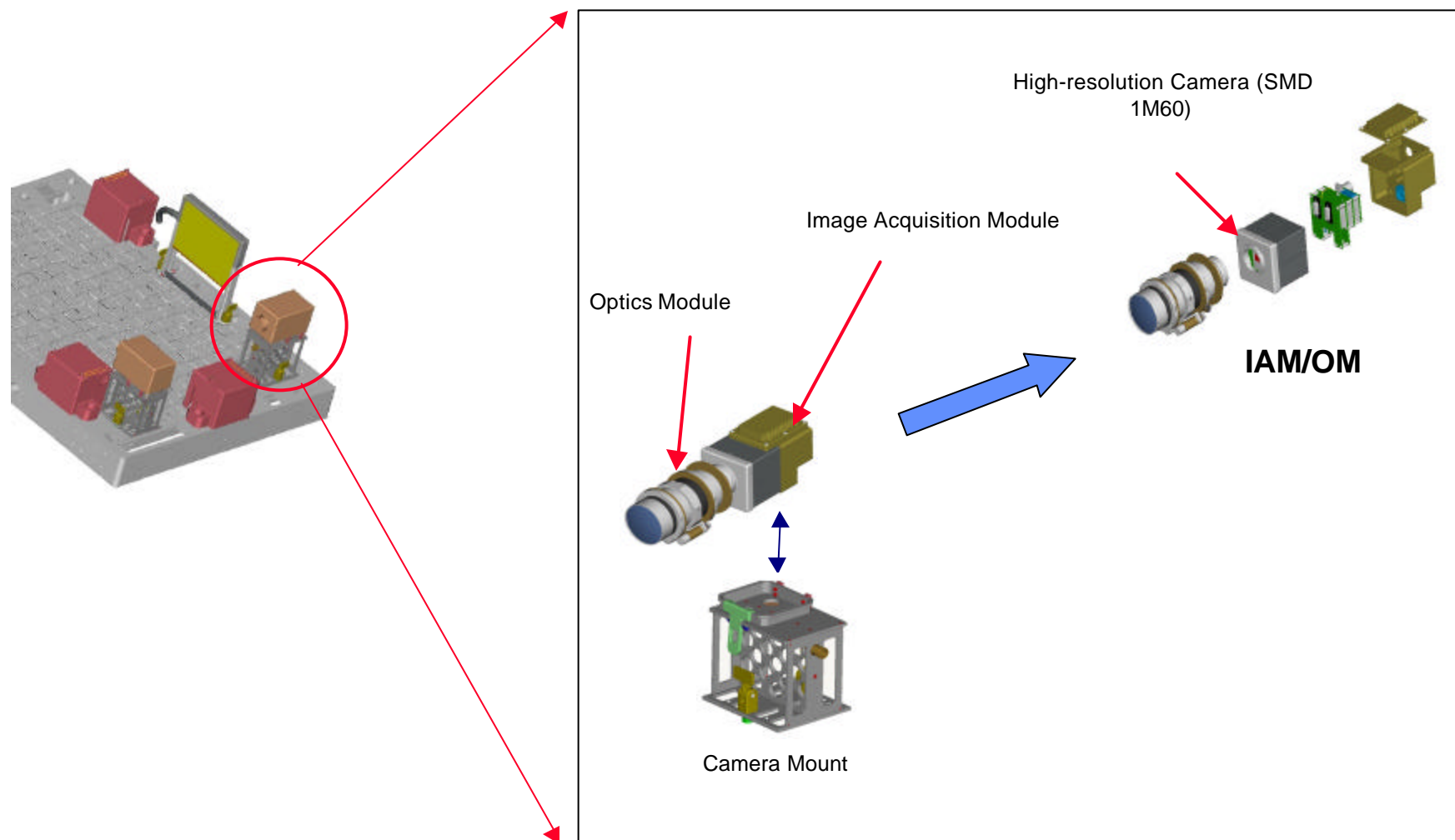
Typically, the B&W cameras will attach to a camera mount on top of the optics plate. They will have the freedom to be placed anywhere within the PI volume by means of the quick-disconnect T-groove plate design. The cameras can also be mounted to the top of the translation stage, or directly to the face of a PI enclosure.

### Cooling

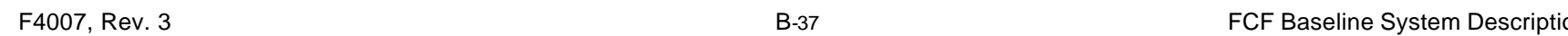
When the camera is mounted on top of camera mount, cooling will be provided through the cooling port, which is located on top of the camera support. Camera outlet air is then vented to the atmosphere.

*The high-resolution camera assemblies that are available to FIR experiments initially on-orbit are shown in the following figures along with electrical block diagram.*

## FIR High-Resolution Camera Assemblies



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### B.2.3.5.3.1.2 Color Camera

**One analog color camera** will have at least  $484 \times 768$  pixels. An electronic shutter will provide exposure times between 1/60 second and 1/10,000 second. In addition, the analog interface may be used by a PI-provided camera if the color camera is not in use. The high-resolution and color cameras consist of 2 parts: the Image Acquisition Module/Optics Module (IAM/OM) that houses the remote camera assembly, and the Diagnostics Control Module (DCM) that houses the support electronics and lens controllers. The IAM/OM can be attached to the wall of an experiment package, or to the top of a camera mount for flexible alignment. A cable will provide the necessary power/data interfaces between the housing and the remote camera assembly.

#### Imaging Interfaces

The imaging assembly interface consists of 3 camera interfaces: two for high-resolution monochrome black and white, and one for analog color. Each digital camera interfaces to an Image Processing and Storage Unit (IPSU). A description can be found in the Command and Data Management System (CDMS) section. The color camera interface is located in the FSAP.

#### Performance

The IPSU will be capable of collecting data at 40MB/second nominally. The IPSU optionally processes the image data using predefined techniques. Processing includes compression, feature extraction, event detection, centroid detection and calculation, and so on. Data will be passed from IPSU memory to permanent storage or directly to the IOP for downlink, bandwidth permitting.

The FIR camera interface will be designed to perform the following tasks:

- Support the general **imaging requirements** of the FIR and its assigned experiments
- Provide **local storage**
- Provide a **channel** to IOP
- Perform **closed-loop control** of an experiment
- Provide **analog output** to FSAP

### B.2.3.5.3.1.3 Ultra-high, Frame-rate (UHFR) Camera

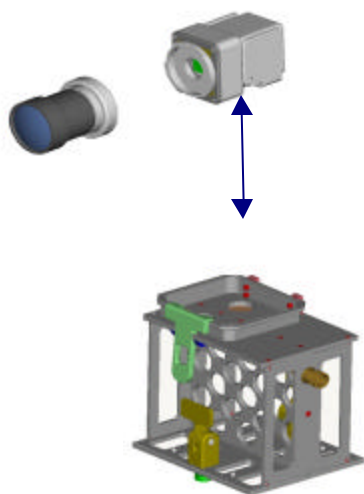
**One ultra-high, frame-rate (UHFR) camera** is envisioned as a standard FIR resource. At a minimum the camera will provide electronic shuttering and contain anti-blooming circuitry. The camera will have sensor array of  $512 \times 512$ . The camera will have the ability to capture images at various frame rates up to 1000 fps. It will have the capability to store at least 1 second of data at 1000 fps at the maximum resolution (more as upgrades become available). More images/recording time can be stored if the image resolution is decreased, or the memory is increased. Images can then be downloaded to the ground or stored on the IPSU as necessary. The camera should have the same lens interface as the existing FIR cameras, enabling the use of existing FIR hardware.

### B.2.3.5.3.1.4 FIR IR Camera

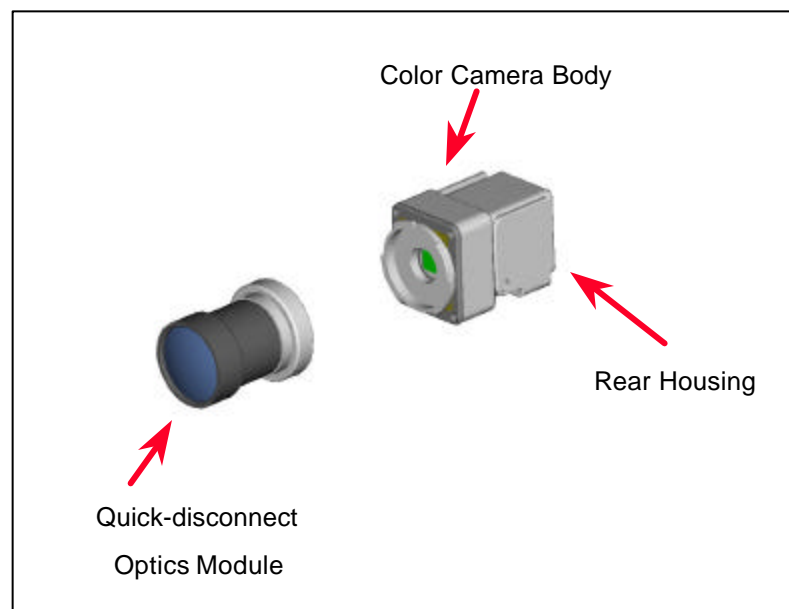
The FIR will provide the capability for a possible future inclusion of an IR camera.

*An overview of the color camera assembly is shown in the following figures along with the electrical block diagrams of the UHFR and color camera.*

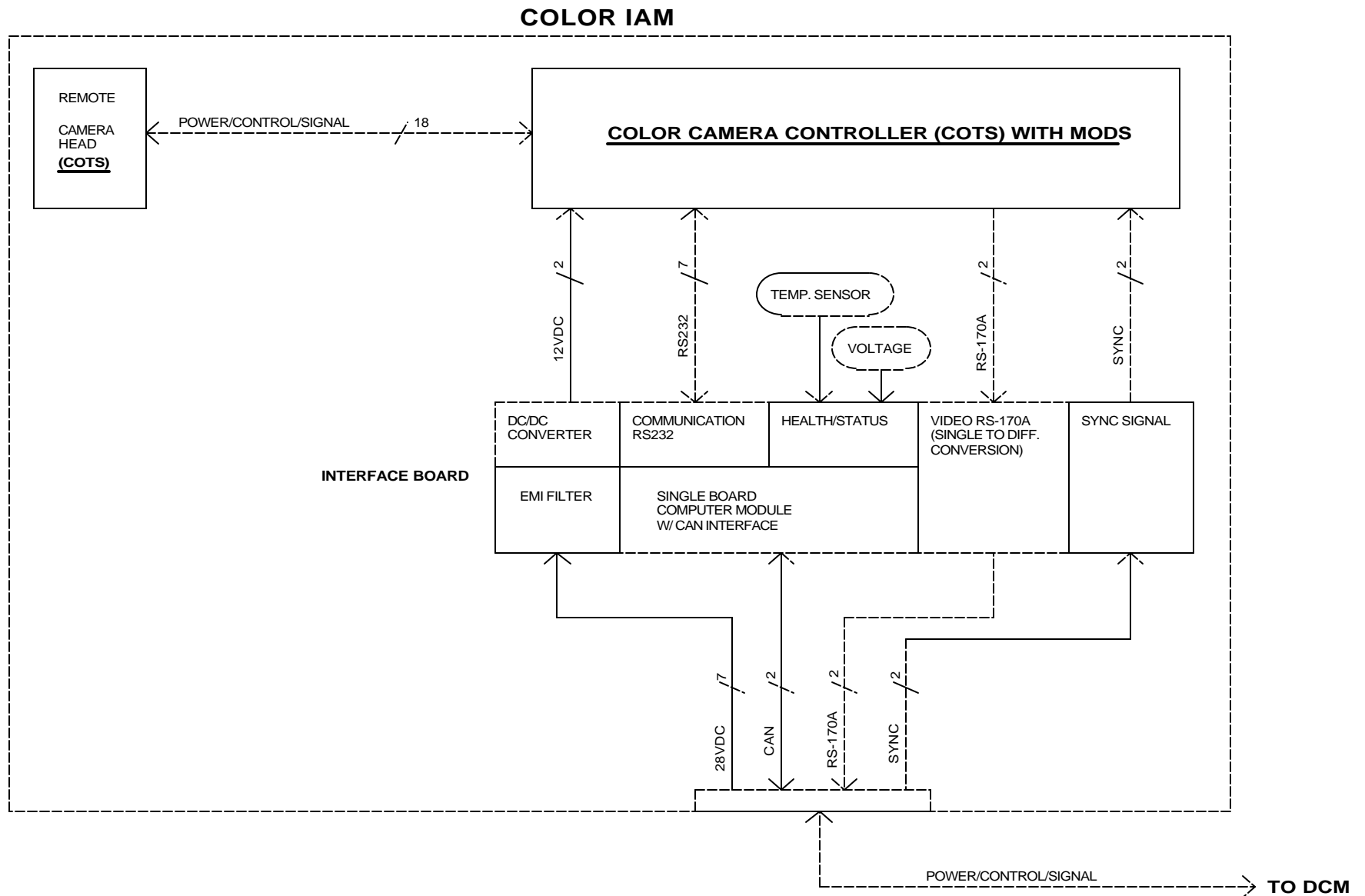
## FIR Color Camera Assembly (Conceptual Layout)



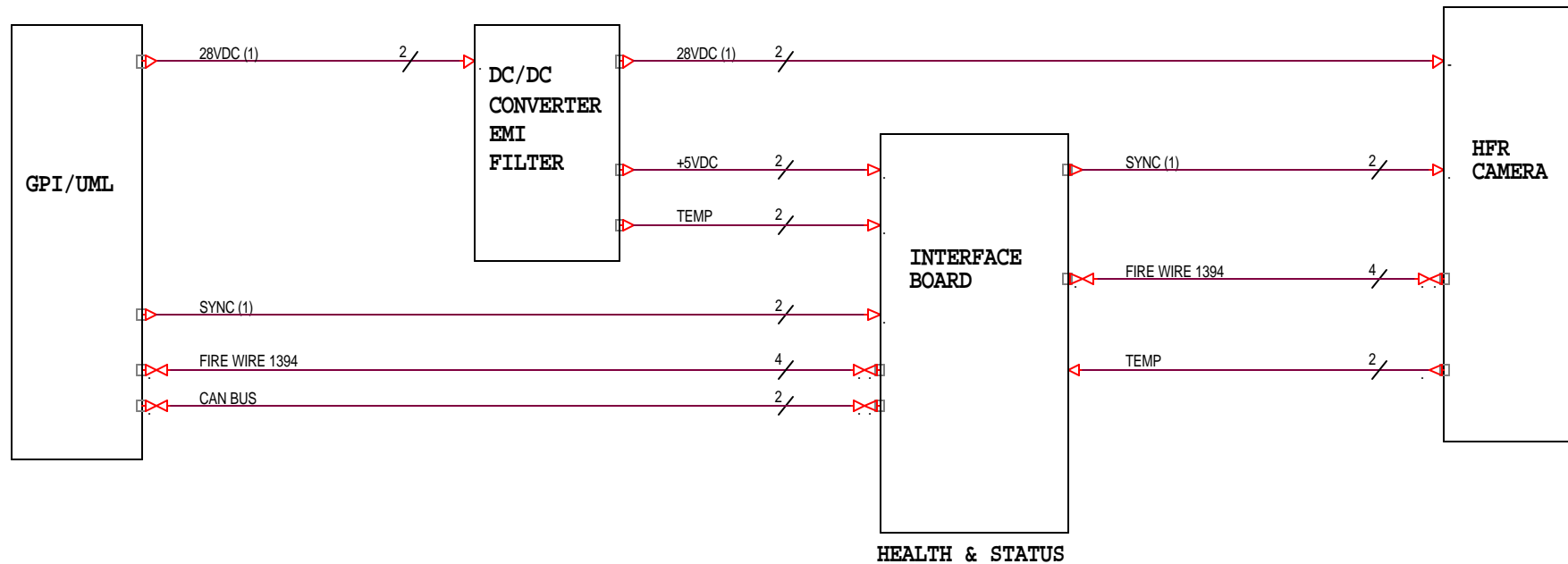
### Image Acquisition Module/Optics Module



## FIR Color Image Acquisition Module Block Diagram



## Ultra High Frame Rate Camera Image Acquisition Module Block Diagram



#### **B.2.3.5.3.1.5 Lens Assembly**

The FIR will provide **four lens systems** for the three FIR provided cameras. The primary lens in each lens package will consist of a motorized zoom and focus lens that can accommodate different sensor sizes, working distances or fields of view using additional lens components. Three of the lens systems will be configured for macroscopic views with one being configured for the color camera sensor. The fourth lens will be configured as a high-magnification lens. The range of fields of view the FIR will accommodate will be (nominally) 300  $\mu\text{m}$  x 300  $\mu\text{m}$  to 100 mm x 100 mm. The lenses are designed such that resolution will be limited by the detectors' characteristics.

The zoom function, as well as the focus and aperture functions of those lenses that employ them will be motorized and remotely controllable. All lenses provided are intended for use in the visible wavelength region of the electromagnetic spectrum.

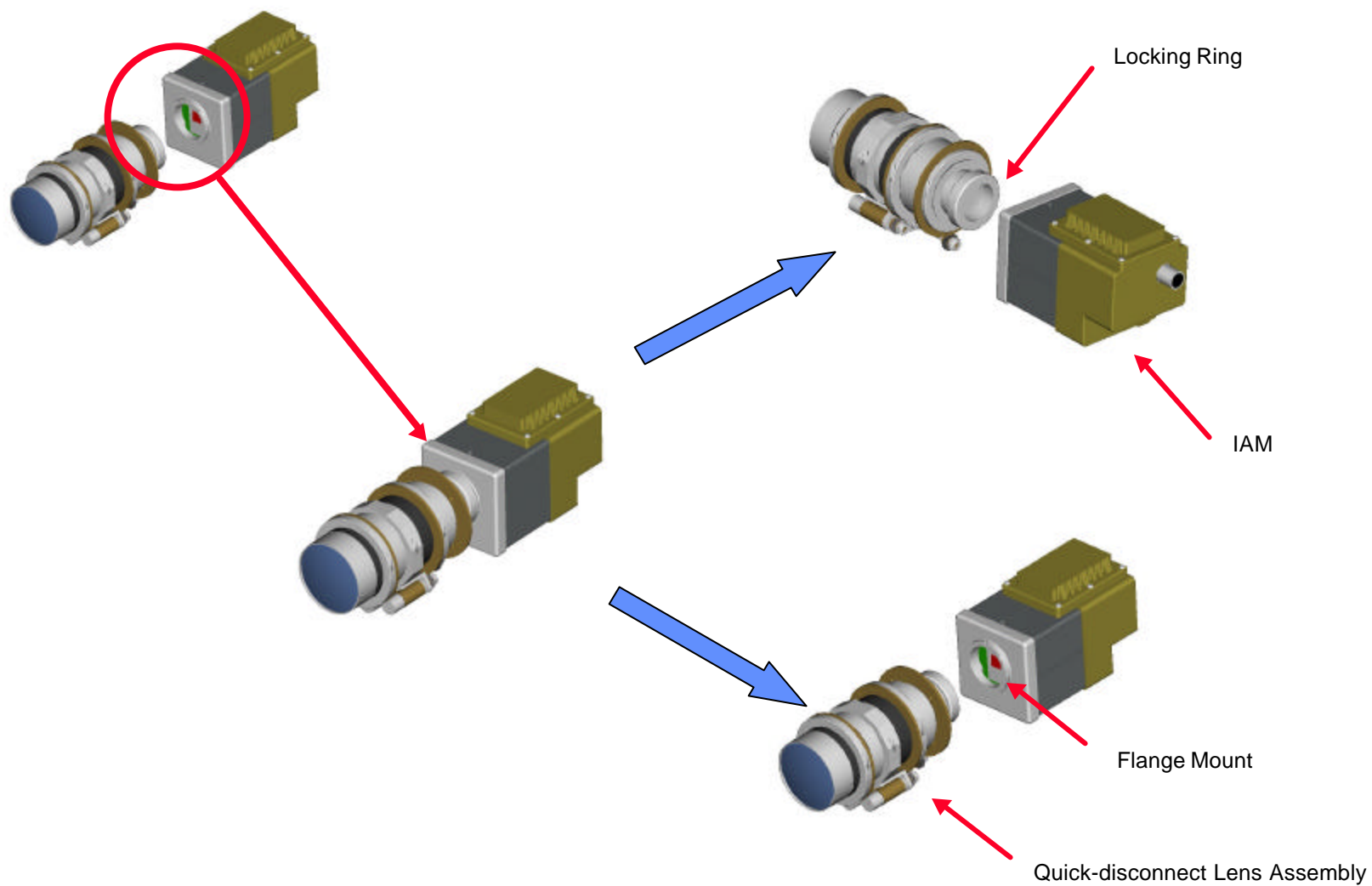
Any heat generated by the motors that are employed on the lens will dissipate via the convective airflow across the optics bench. The amount of heat to be dissipated is anticipated to be less than 1W (for each lens).

#### **Quick-disconnect Lens Mount**

A quick-connect mount that is common with CIR will be used to interface the lenses to the camera. The quick-disconnect lens mount will allow for commercial lenses to interface to the FIR cameras without changing any of the critical distances (such as, flange-to-sensor distance). The quick-disconnect lens mount is attached to the lens assembly (Optics Module). By rotating the locking ring, the Optics Module can be connected/disconnected from the IAM. The lenses will be interchangeable between any camera assembly with this interface, but lens component changes may be necessary if camera sensor sizes are different. In addition, the PI has the option to replace a camera lens with a specific lens to accommodate specific experiment needs.

*The FIR quick-disconnect lens mount design is shown in the following figure.*

## FIR Quick-disconnect Lens Mount



### Zoom

The field of view ranges from 24 mm  $\times$  24 mm to 100 mm  $\times$  100 mm at a working distance of about 0.75 meters (2.5 ft) from the camera face when used on the high-resolution camera. Again, this lens will operate in the visible region.

### Macroscopic Lens

The macroscopic lens that is primarily for use with the high-resolution camera is a 35 mm format zoom lens that is adapted to work with a Charged Coupled Device (CCD) camera. The zoom function, as well as the focus and aperture functions of each lens can be motorized and remotely controlled. The focal length can be varied through a range of 70 mm to 180 mm. The maximum aperture is f/4.5 at 70 mm focal length, and f/5.6 at 180 mm.

At the shortest working distance (120 mm from the vertex of the objective lens to the object), fields of view between 19 mm  $\times$  19 mm and 46 mm  $\times$  46 mm can be obtained with the high-resolution camera. At a 390 mm working distance, fields of view ranging from 40 mm  $\times$  40 mm to 100 mm  $\times$  100 mm can be obtained. Larger fields of view can be achieved if the experiment configuration allows for longer working distances. If used with the color camera, the system field of view will be smaller due to the smaller sensor size. A close-up lens attachment can be used to increase magnification and to decrease working distance.

The macroscopic lens that is primarily used with the color camera is a **motorized zoom lens** that allows for application-specific configurations by interchanging the lens components. This lens will be configured for fields of view over the range of 9.7 mm  $\times$  12.9 mm to 97 mm  $\times$  129.4 mm on the color camera sensor. Again, the sensor is the limiting factor in resolution. The **dimensions** of the **Nikon lens** are 16.5 cm in length  $\times$  13.97 cm in diameter (6.5 in. in length  $\times$  5.5 in. in diameter), and the volume is equal to 2523.6 cm<sup>3</sup> (154 in<sup>3</sup>) quantity of 2. The dimensions of the **Navitar lens** are 20.96 cm in length  $\times$  11.43 cm in diameter (8.25 in. in length  $\times$  4.5 in. in diameter), and the volume is equal to 2146.7 cm<sup>3</sup> (131 in<sup>3</sup>).

### High-magnification Lens

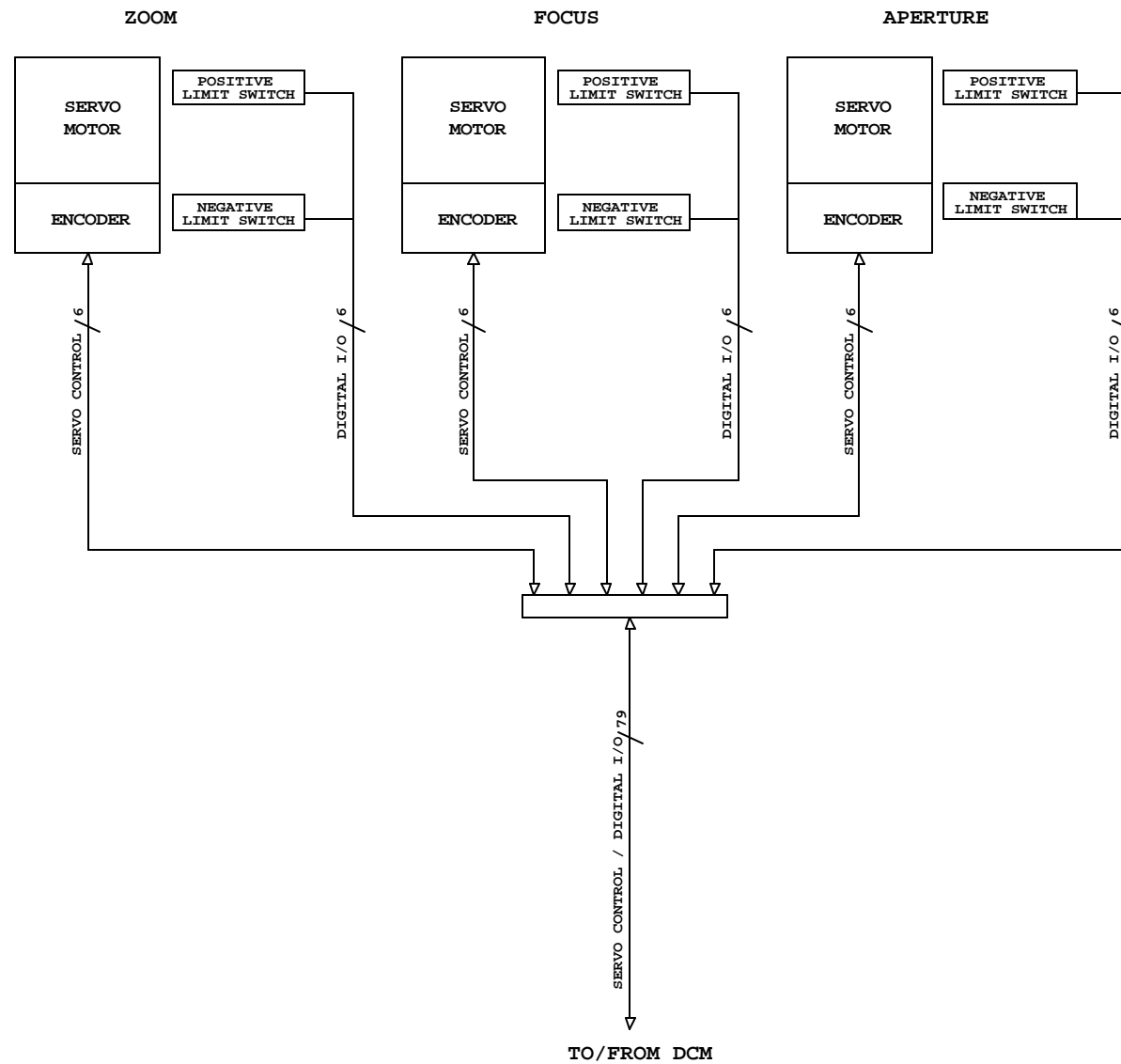
The motorized, high-magnification lens system features a 10:1 zoom ratio and a modular design that allows for application-specific configurations by adding lens attachments of various magnification or by employing the use of the coaxial illumination port. This lens will be primarily used on the high-resolution camera and will be configured for a 250  $\mu$ m  $\times$  250  $\mu$ m to 14 mm  $\times$  14 mm range at a minimum of 32 mm working distance. The sensor will be the limiting factor in resolution. All lens functions (aperture, focus, zoom) can be remotely controlled. The **dimensions** of the Optem (high magnification lens) are 30.48 cm in length  $\times$  15.24 cm in diameter (12 in. in length  $\times$  5 in. in diameter), and the volume is equal to 4096 cm<sup>3</sup> (250 in<sup>3</sup>).

### Focusing

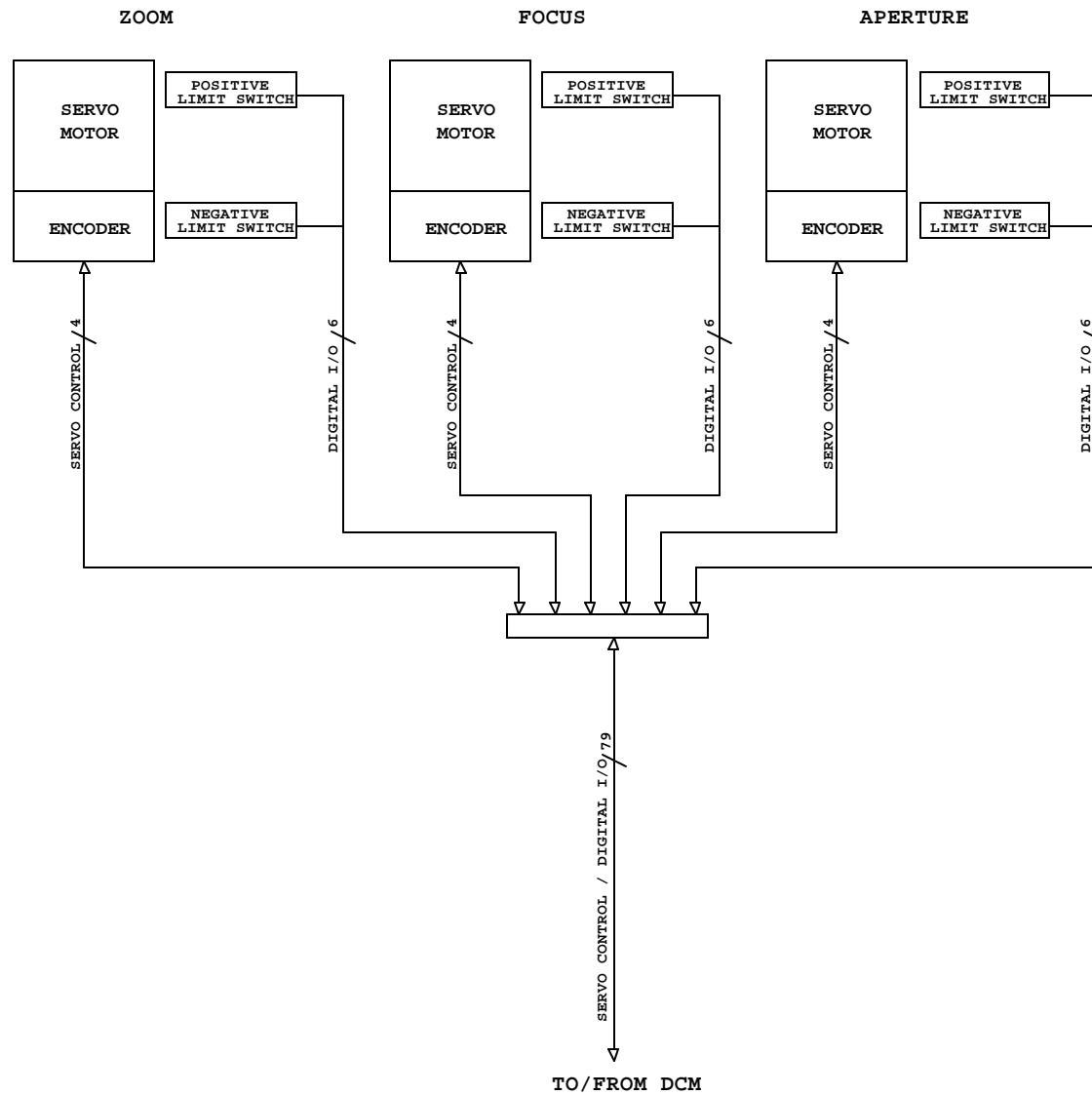
Automated focusing is achieved with motorized lenses and a closed loop focus control system. Focusing is a sensitive function of object range, the initial focal range of the imaging system, and the spatial spectrum of the object. A processing algorithm is implemented in either the IPSU or the FSAP to analyze digital camera images for the spatial frequency information in particular. An algorithm is used to process an array of pixels to determine the image spatial frequency content. The IPSU or FSAP controls the camera lens motors via DCM to move one way or another until the algorithm has encountered the image with the highest spatial frequency.

*The electrical block diagrams of the macroscopic, high magnification, and color lens assemblies are shown in the following figures.*

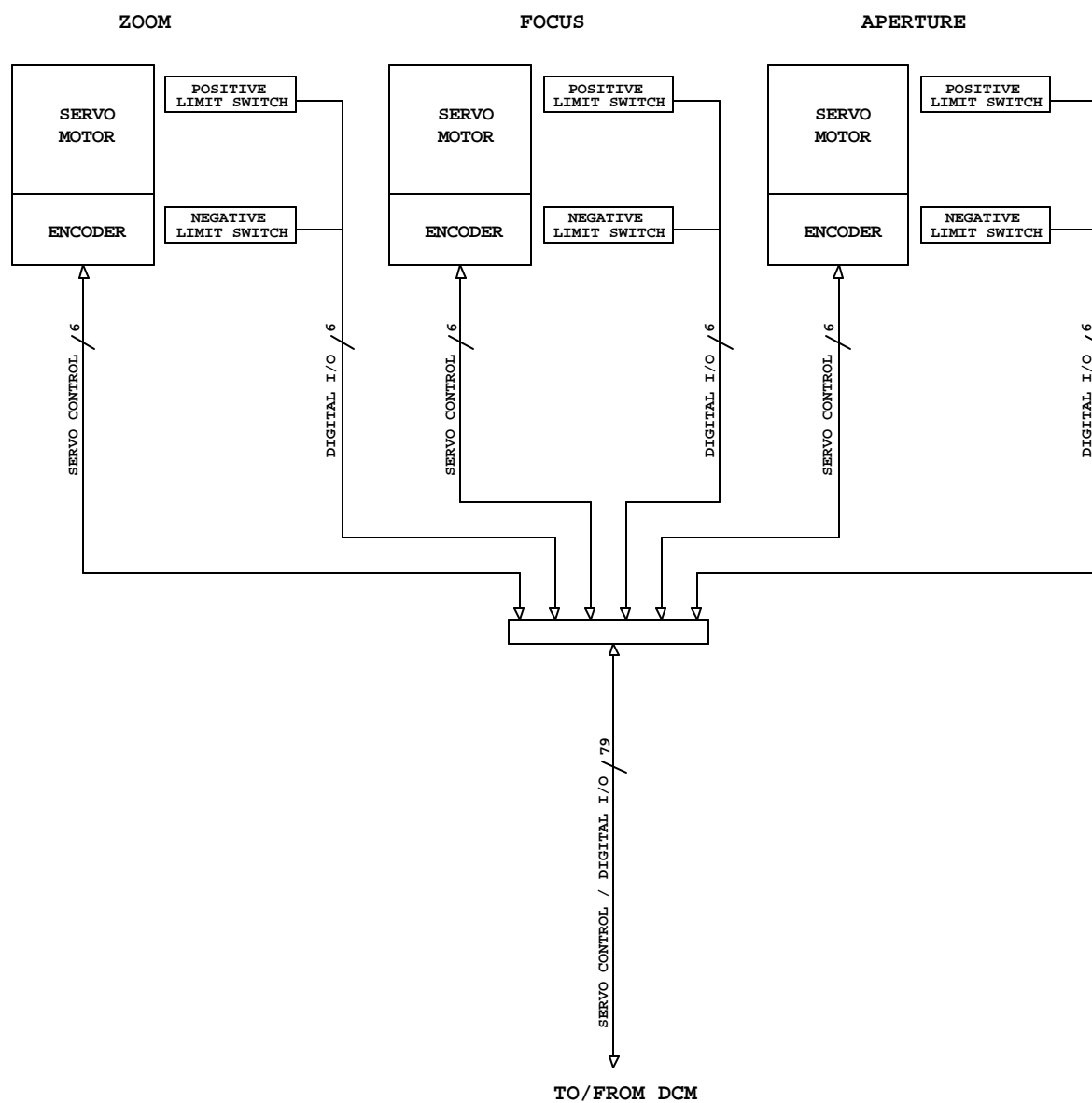
## Macro Lens Assembly Block Diagram



## High Magnification Lens Assembly Block Diagram



## Color Lens Assembly Block Diagram



#### B.2.3.5.3.1.6 Optical Components

The following components will be provided by the facility and will aid in forming optical paths and optical alignment, and in automated position and tracking.

##### **Mirror**

The FIR will reflect test cell imagery to the cameras when necessary using a 10.16 cm (4 in.) diameter front surface mirror. Mirror surface quality will be sufficient ( $\lambda/10$  flatness) to ensure no noticeable degradation in image quality in the visible wavelength region (380 nm - 770 nm). The mirror will be Gimbal-mounted to provide low-rate scanning and optical alignment of the test cells.

Gimbal Optic Mounts will have 2 axis rotation for pan and tilt, with 0.3 arcsec of resolution to perform scanning and optical alignment. The mount will accommodate a mirror 10.16 cm (4 in.) in diameter. Quick-disconnect/connect interfaces will be designed into the mounts for easy reconfiguration of optical paths.

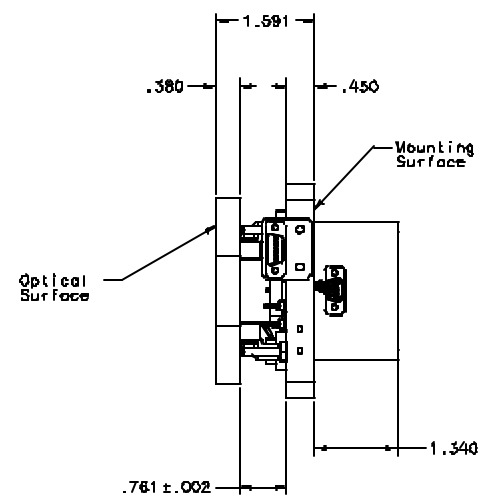
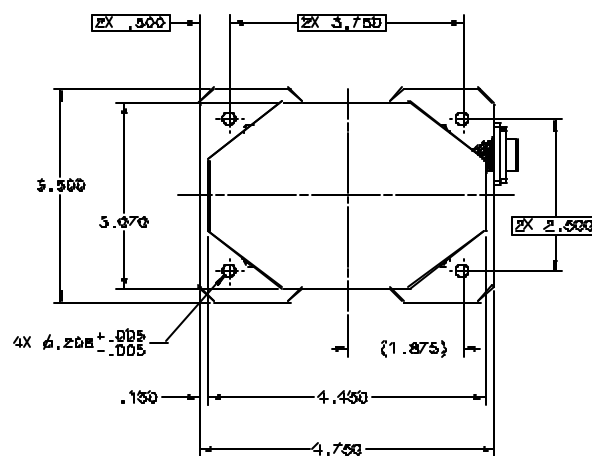
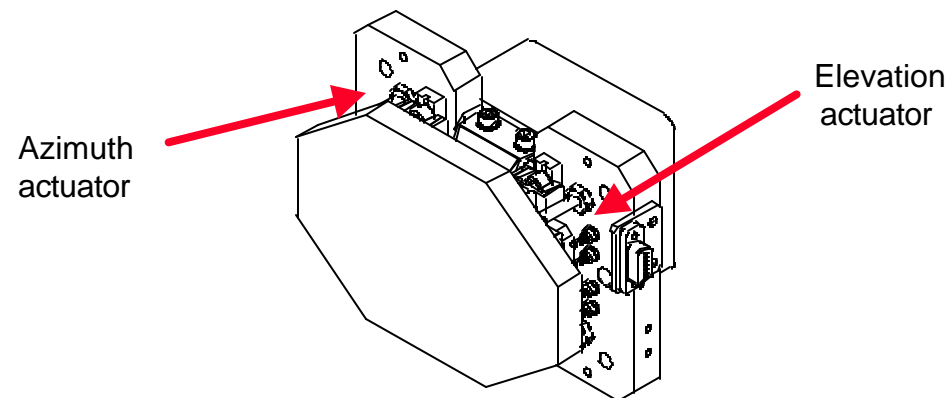
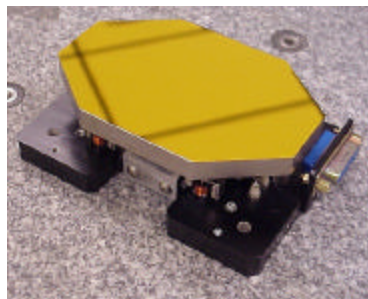
An analog signal will be provided to the FSAP (Automated Position and Tracking [APT] System) which will perform tracking. The system will provide azimuth and elevation of the target being tracked within the field of view. That data will be used by the computer to control the movement of a gimbal mounted mirror.

##### **Linear Translation Stage**

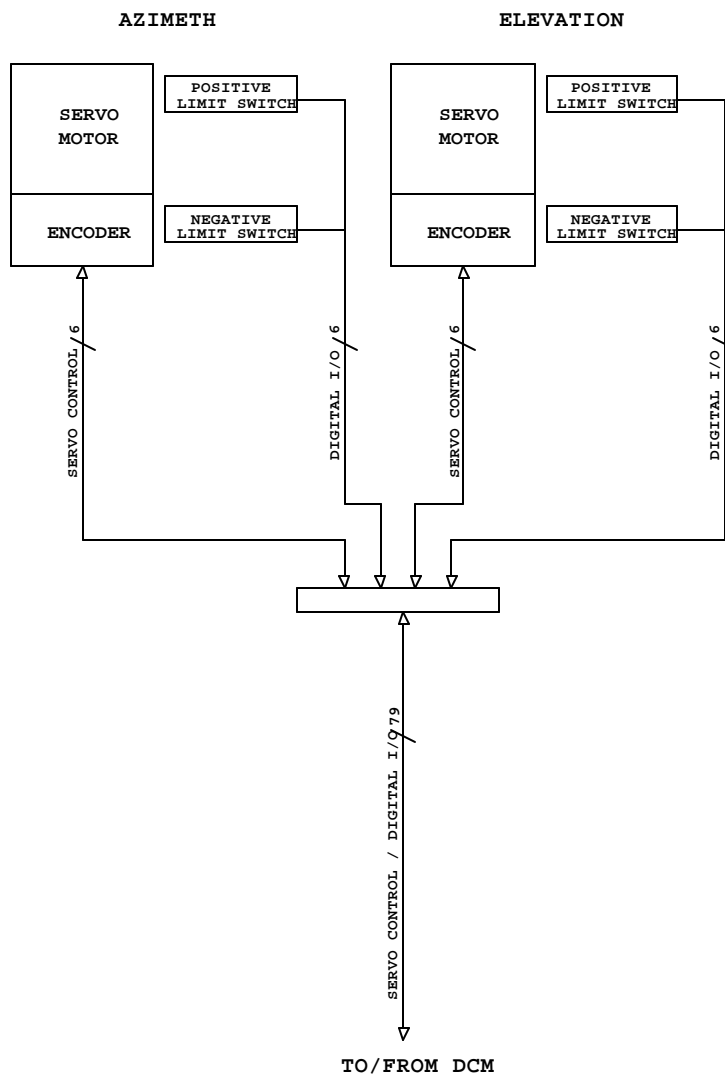
The Linear Translation Stage will support optical alignment in the x and y direction, and camera focusing in the z direction on one of the camera assemblies which will support microscopic imaging. Each translation stage will have +/-12 mm of translation. Resolutions of the stages will be less than 2  $\mu\text{m}$ . The stages will be servo-motor driven, and have standard dimensions of approximately 15 cm (W)  $\times$  22 cm (L)  $\times$  11 cm (H) [5.9 in. (W)  $\times$  8.7 in. (L)  $\times$  4.33 in. (H)]. This stage will be passively cooled due to its intermittent operation and low wattage per axes. The servo motor is coupled to a 879:1 zero backlash gear box, and is coupled to a 16 ppr encoder. The gear box and the encoder along with the 16 TPI lead screw will allow for <2 micron resolution.

*The gimbale mirror concept and its electrical block diagram are shown in the following figures as well as the translation stage concept and block diagram..*

## FIR Gimbaled Mirror Assembly Concept

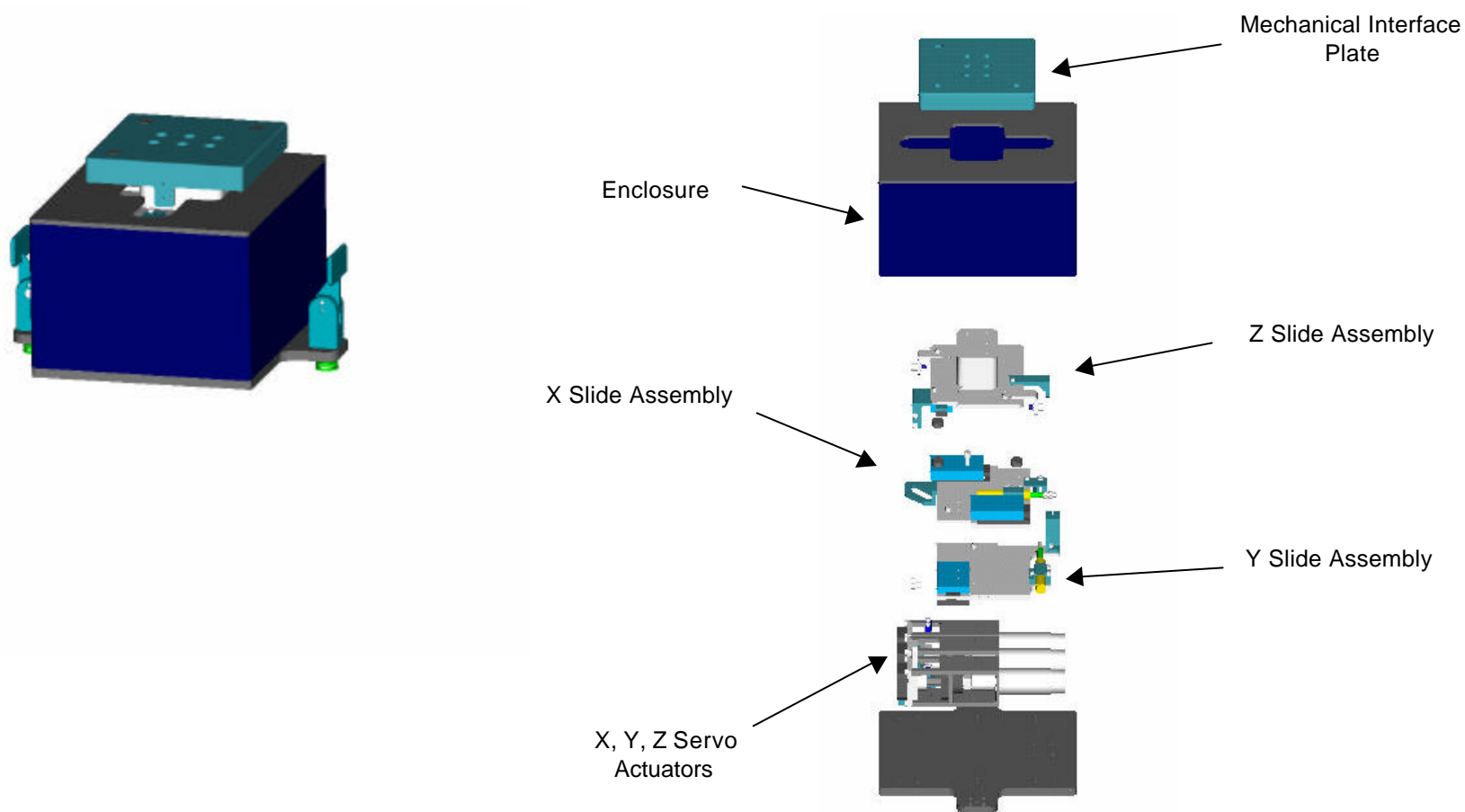


## Gimbaled Mirror Block Diagram

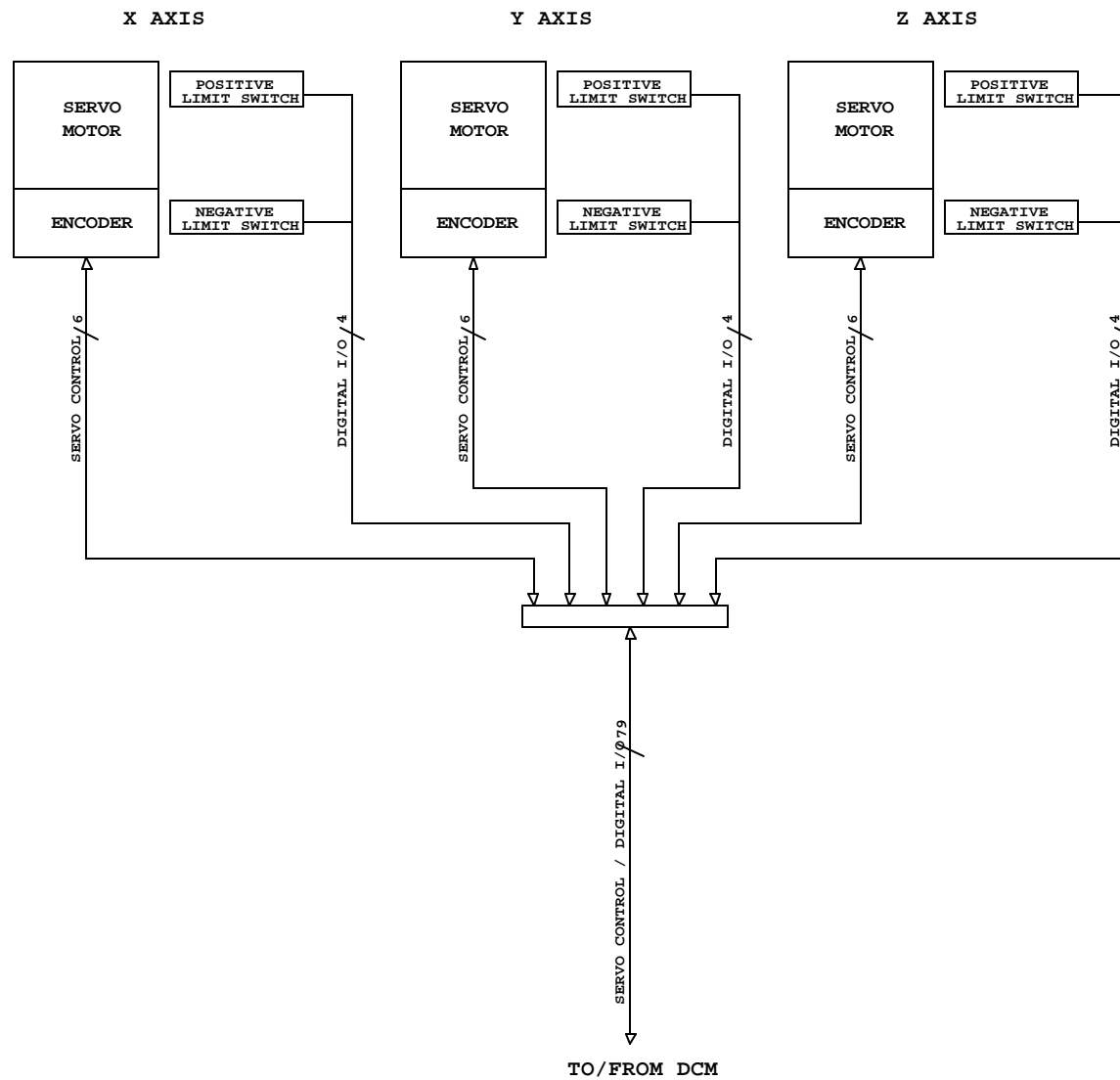


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## FIR Translation Stage Assembly Concept



## Translation Stage Block Diagram



#### **B.2.3.5.4      Technical Description of the Illumination Packages**

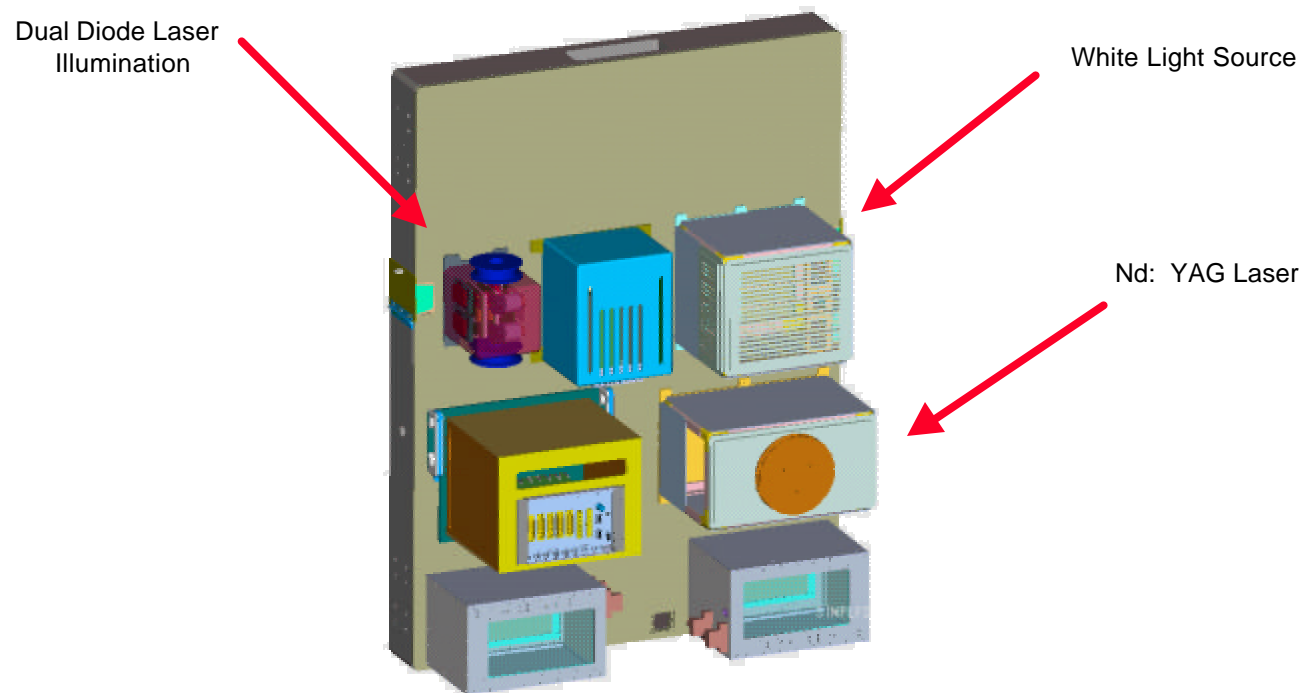
The FIR will supply illumination to enable the cameras to obtain meaningful images of scientific phenomena. Several illumination packages will be available to sufficiently illuminate a range of test cell sizes and to provide a range of illumination demands, such as polarized or collimated light and/or a backlight. The capability to vary the output intensity of each package will also be provided.

*An overview of the FIR Illumination and Laser  
Assemblies is shown in the following figure.*

## Overview of the FIR Illumination and Laser Packages

### Illumination and Laser Packages:

- White Light via Fiber Weave
- Laser Diodes
- Nd: YAG



#### B.2.3.5.4.1 Performance Requirements

The **backlights** are required to be uniform and fully illuminate an experiment test cell, but must not cause heating of the test area. Continuous backlighting is required. A white light source is necessary for imaging. The FIR will provide a range of light intensities, between 0.01 mW/cm<sup>2</sup> and 0.3 mW/cm<sup>2</sup>, at the test cell using a white light backlight.

The facility will provide 3 lasers in the initial complement. Well-conditioned power supplies (diode drivers) will be supplied to support facility-provided diode lasers.

The lasers provided will be located away from thermally sensitive components in the EP. The exceptions to this are PI-provided diode lasers, which may be integrated with the experiment but will be powered by the facility. The light from each laser source will be transmitted to the experiment through single mode optical fibers which will have an industry-standard optical fiber interface. As with the white light, the fibers will be routed through bench feedthroughs that are located on the sides of the optics plate in order to avoid the losses that are associated with using connectors.

Two laser beam collimators which attach to the end of single mode fibers will be supplied. The collimators will be a fixed diameter, 50 mm and 25 mm. The collimators will be specific to fiber core diameter and divergence angle; therefore, collimators may only be interchangeable between lasers with similar optical fibers. Use with other fibers will result in a smaller collimate beam with reduced beam quality.

#### B.2.3.5.4.1.1 White Light Assembly

The FIR will provide a white light assembly to acquire color images. Use of a broadband spatially incoherent source is useful in preventing “ringing” in the image, which occurs with the use of spatially coherent light. The white light assembly consists of two bulbs, packaged with their respective power supplies, controller circuitry, health and status circuitry, and containment envelope. The white light assembly will be located on the back of the optics plate to prevent heating the test cells. Two fiber bundles (fiber cables) will come from the output of the light source. One fiber cable will terminate into a fiber weave panel with a uniform area that measures at least 10 cm × 10 cm (3.9 in. × 3.9 in.) The other fiber bundle cable will terminate into a ferrule. The ferrule will accommodate a focusing lens or allow attachment to PI-specific hardware.

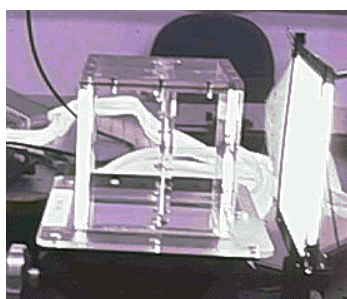
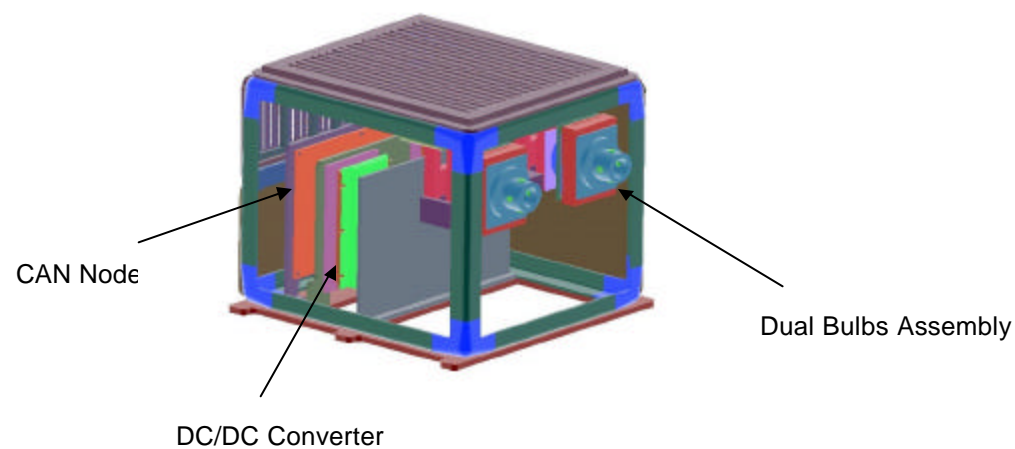
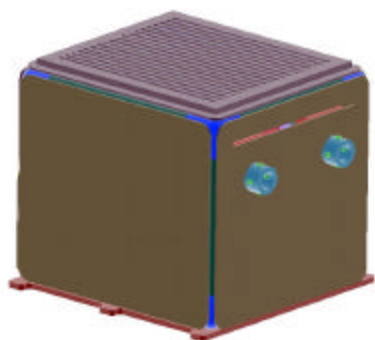
The fiber bundles will be fed through openings at the sides of the optics plate. The option exists for PI-provided fiber bundles or large core fibers to deliver the illumination to the experiments to be shaped or dispersed by the experiments.

The woven fiber panel will provide uniform lighting, while only requiring a small volume. The panel can be used as back-lighting for a test cell or area lighting for more volume illumination. The panel will be approximately 145 mm × 140 mm (5.7 in. × 5.5 in.) in size, and the center [100 mm × 100 mm (3.9 in. × 3.9 in.)] will provide uniform intensity. When this area is imaged, the standard deviation of the gray level value is less than 13% of the mean.

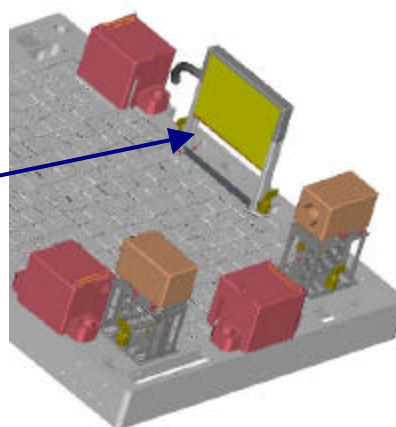
The use of the fiber optics panel and bundle isolates the test cell from heat because infrared radiation will be removed from the illumination using infrared filters before coupling into the fiber bundles. Hardware will be provided to attenuate the light +/-10% of the bulb's rated voltage. The stability of the white light sources will be better than +/-3%.

*The physical layout of the White Light assembly is shown in the following figure.*

## FIR White Light Assembly



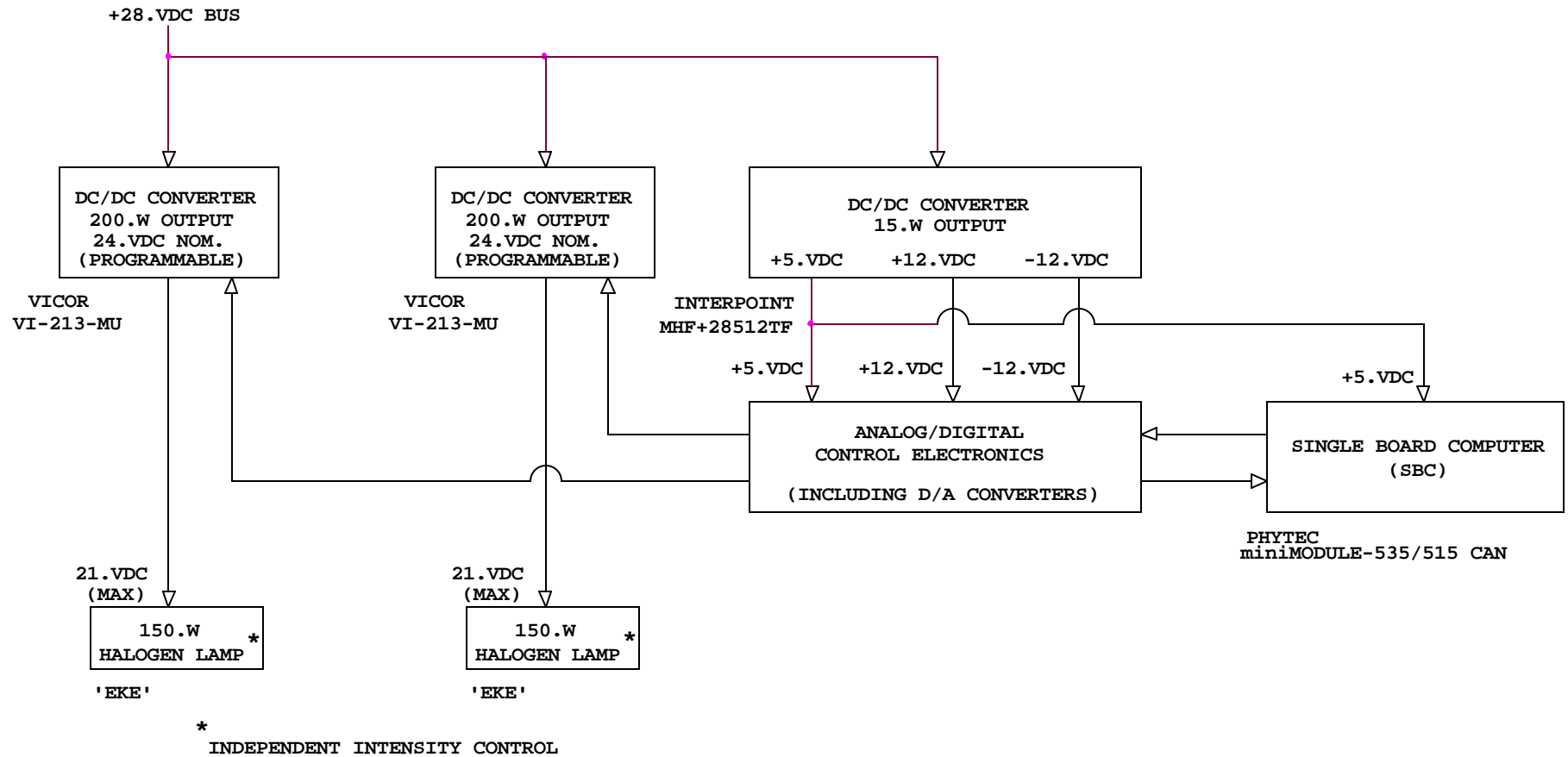
Fiber Weave Panel Illumination of a Test Cell



Fiber Weave Light Distribution

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## Dual White Light Package w/Independent Intensity Controls Electrical Block Diagram



#### B.2.3.5.4.1.2 Nd: YAG Laser Assembly

**Laser #1** is a diode-pumped, solid-state, frequency-doubled Nd: YAG laser with a wavelength of 532 nm. The beam will be a “high quality” beam that is suitable for critical applications, as well as have sufficient power to illuminate relatively large test cell areas. The laser light will be delivered to an experiment via single-mode, polarization-maintaining optical fiber with FC/PM connectors. The delivered laser power will be at least 50 mW after passing through one connector on the PI hardware, and linearly polarized with a polarization ratio of 100:1. The FIR will align the polarization axes between the fiber and the laser to prevent polarization rotation in the optical fiber due to low mechanical or thermal stresses. The numerical aperture of the optical fiber will be 0.11.

The laser’s coherent length will be approximately 30 meters and the stability over eight hours will be +/-1% of the delivered mean power. Through mechanical attenuation, the power that is delivered to an experiment will be varied to meet the needs of an individual PI. A fiber-coupled photodiode will be used to monitor and control the laser output power.

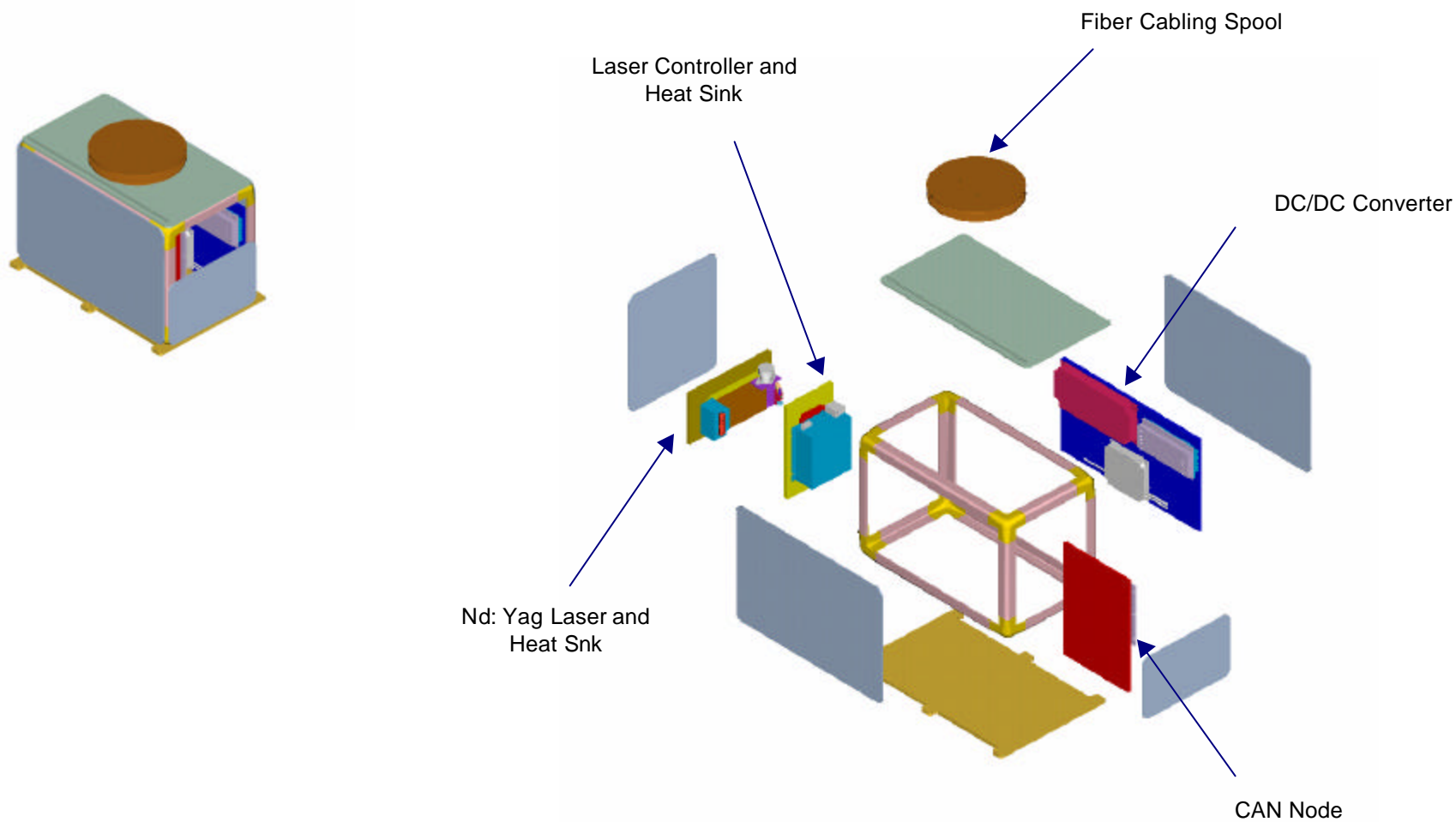
The Nd: YAG laser is a solid-state laser whose active medium is a small cylinder of doped yttrium aluminum garnet ( $\text{Y}^3\text{Al}^5\text{O}^{12}$ ). The 1064-nm output of the laser is converted to 532 nm through the use of a frequency-doubling crystal. The pump radiation for this laser is provided by a diode laser whose wavelength is approximately 800 nm. All of these components are contained inside the laser head, which is quite small—the longest dimension typically measures around 150 mm (5.9 in.). The inclusion of the diode laser as part of the laser assembly has implications for both the temperature control needed to operate the laser and for the laser’s expected lifetime. Active cooling is required to ensure stable operation.

The Nd: YAG laser assembly has a heat sink that is attached to the bottom of the laser head to carry heat away from the head. The entire laser package is placed over an air intake port. Air will be sucked into the port, directing the hot air through the bench and into the heat exchanger. Cool air is then expelled and flows over the top of the bench. The heat to be dissipated is approximately 70 watts.

The **dimensions** of the Nd: YAG laser are 25.3 cm × 17.7 cm × 21.03 cm (9.96 in. × 6.96 in. × 8.28 in.), and the volume is equal to 9344.6 cm<sup>3</sup> (570.2 in<sup>3</sup>).

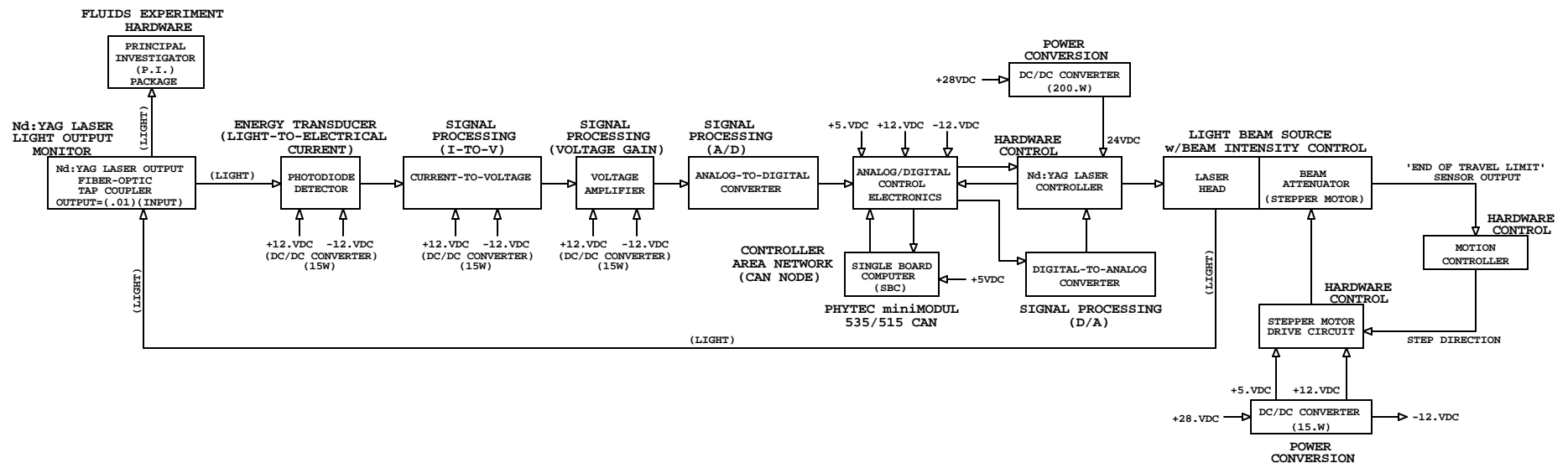
*The preliminary physical layout of the Nd: YAG Assembly is shown in the following figure..*

## Nd: YAG Laser Assembly



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## Nd:Yag Laser Package Electrical Block Diagram



#### B.2.3.5.4.1.3 Laser Diodes Assembly

**Laser #2** and **Laser #3** will be two 680 nm, +/-10 nm diode lasers. The FIR Laser Diode assembly will contain both of these lasers. The line width of each laser will be less than 1 nm. The output power of the lasers will be variable up to the maximum output power level of 10 mW for each laser. For flexibility in experiment configuration, both lasers will be fiber pigtailed. The maximum power output at the fiber end for these lasers will be 10mW.

Each laser is packaged within the dual laser diodes assembly enclosure, and housing 2 diodes, 2 thermal electric coolers, 2 diode drivers, and 2 temperature controllers. The fiber pigtail connection is ruggedized using epoxy to maintain the critical alignment between the fiber and the laser during harsh vibrational and shock environments.

Direct-Current-to-Direct-Current (DC/DC) converters will provide the appropriate laser system operating voltages. This dual-package design will permit the sharing of certain hardware resources (such as, the CANbus node and the DC/DC converter for the control and interface electronics.)

#### B.2.3.5.4.1.4 Laser Beam Collimating Optics Assembly

The FIR will supply the following two laser beam collimators: one to produce a 50 mm diameter beam and one to produce a 25 mm diameter beam.

The **25 mm diameter collimator** will be an off-the-shelf optical package that will be modified to allow for a Fiber Connector (FC) terminated optical fiber to attach to the input. The performance of the collimator will be such that the divergence of the collimated output will be less than 1.5 mrad. This collimator will be used with the Nd: YAG laser assembly and with the diode laser assembly, which both use the same type of delivery fiber.

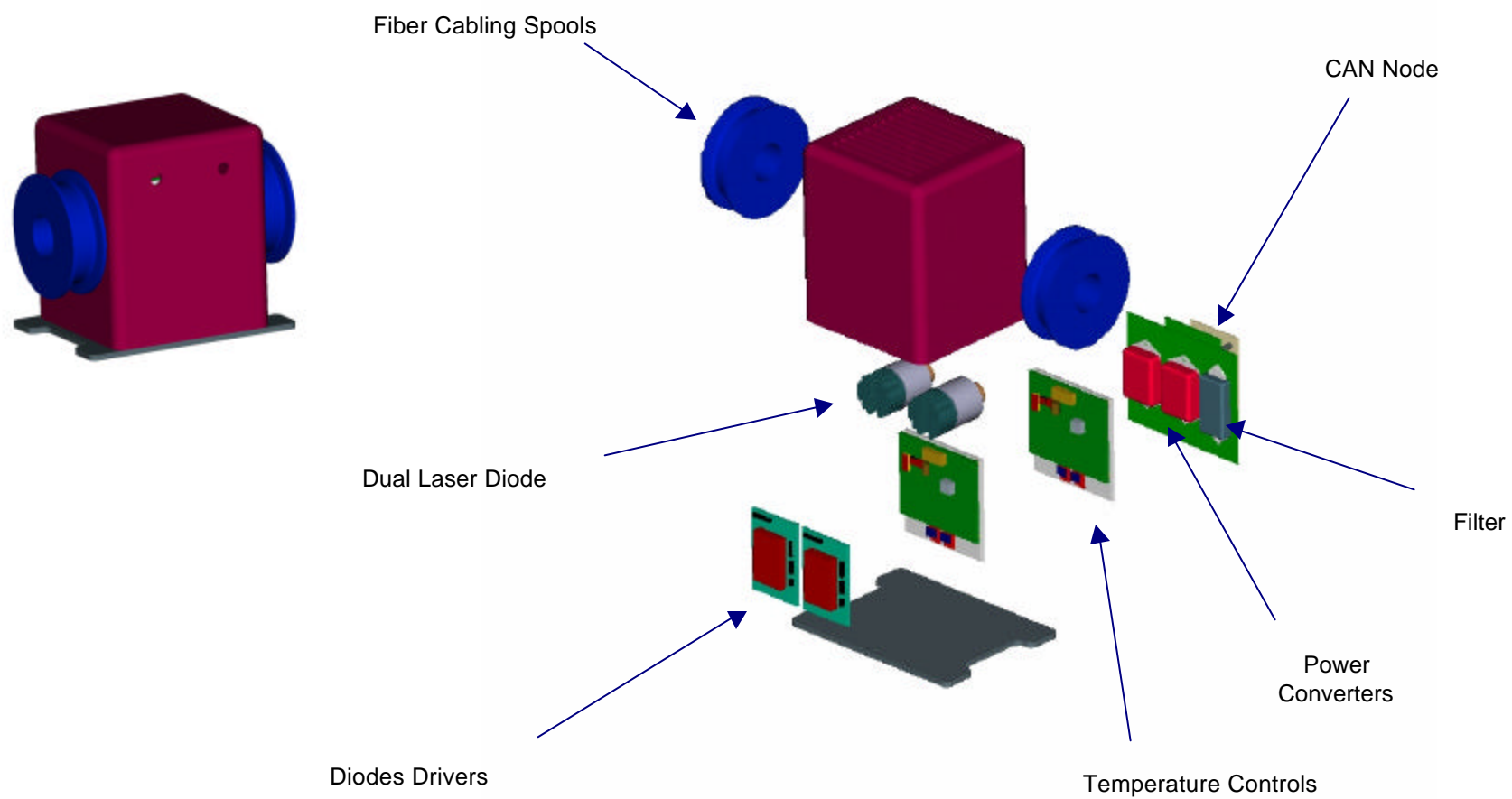
The **50 mm diameter collimator** will also be an off-the-shelf optical package that can be moved to any bench location without necessarily attaching to the experiment package. This optical package will be stored on the back of the rack. The beam divergence will be less than 0.8 mrad. This collimator will also be used for both the Nd: YAG laser and for the diode laser.

Both collimating optics assemblies are optically designed to operate over a broad band. However, there still exists a degree of wavelength dispersion in the optical design, especially over the wavelength separation between the Nd: YAG laser (532 nm) and the diode laser (685 nm). This wavelength separation will be accounted for by employing a dual-position FC connector to connect the fiber from either laser package to the collimator input, and to ensure optimum performance.

The **dimensions** of the **25 mm diameter collimator assembly** are approximately 100 mm in length and 44.5 mm in diameter (3.9 in. in length and 1.75 in. in diameter). The dimensions of the **50 mm diameter collimator assembly** are approximately 218 mm in length and 67 mm in diameter (8.6 in. in length and 2.64 in. in diameter).

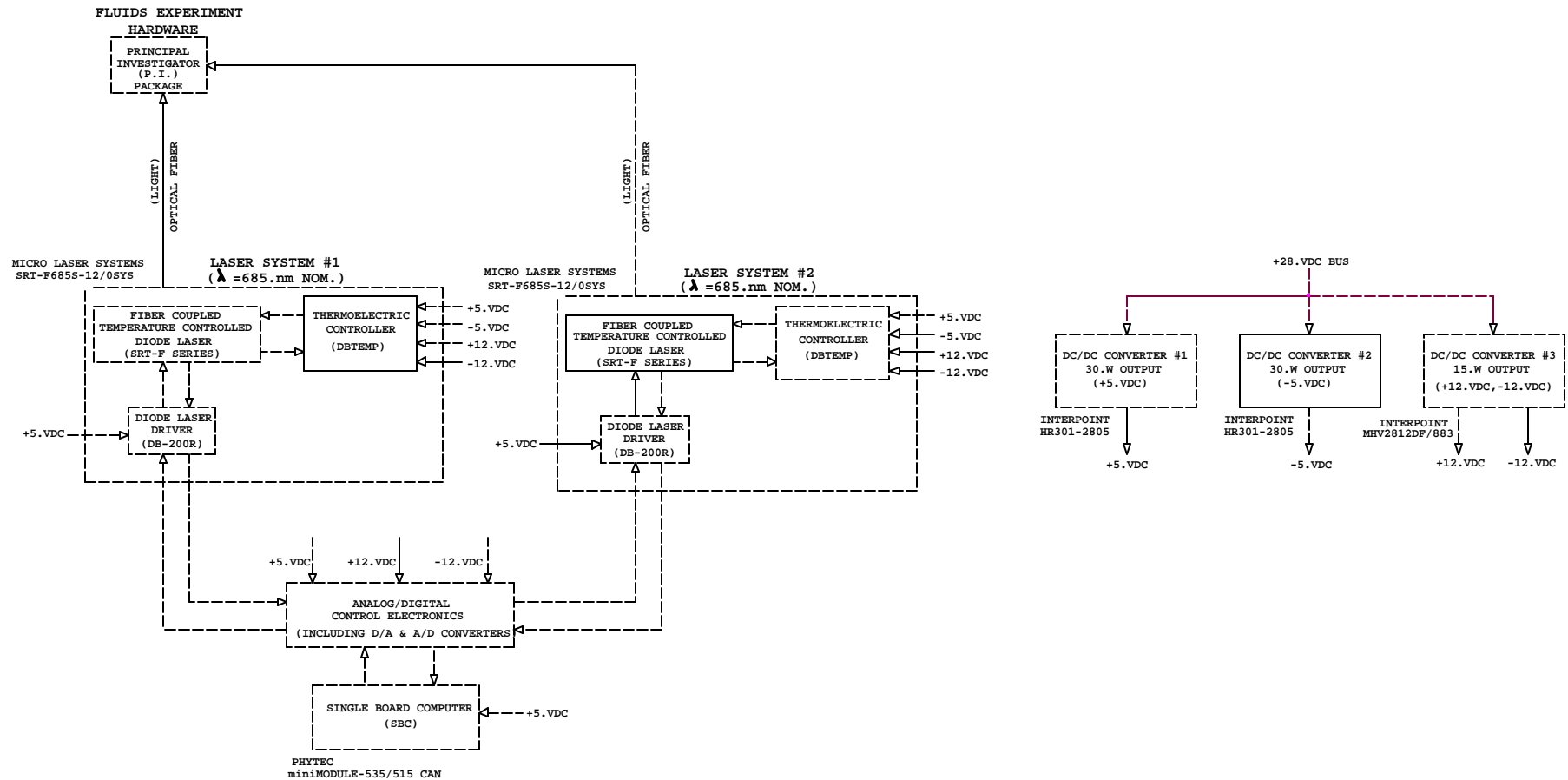
*The preliminary physical layout of the Laser Diode Assemblies is shown in the following figure..*

## FIR Laser Diodes Assembly



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## Laser Diodes Assembly Electrical Block Diagram



## B.2.3.6 FIR Command & Data Management Subsystem

The FCF FIR Command and Data Management System (CDMS) includes all hardware and software to provide command, control, health and status monitoring, data acquisition, data processing, data management, timing and crew interface functions between the Input/Output Processor (IOP), Fluids Science Avionics Package (FSAP), Common Image Processing and Storage Units (IPSUs), Diagnostic Control Modules (DCMs), FIR diagnostics, and the science packages. This section discusses how each of the FIR CDMS elements interface at a system level. The CDMS also consists of a crew interface via the Space Station Support Computer (SSC) and command, data, and video interfaces to the ISS Command and Data Handling System. These elements of the CDMS are discussed in the SSC and IOP sections respectively.

The interfaces between each of the CDMS components is displayed in the following charts, including the FIR CDMS block diagram and rack model showing where each of the elements resides. Primary features of the CDMS include ethernet, avionics CAN bus, PI CAN bus, analog and digital video routing, time synchronization, Sync bus, data storage and PI interfaces. Each element is discussed separately below. Details of where the commanding, health, and status functions are performed in the CDMS are provided in each element discussion.

### B.2.3.6.1 Communication

#### B.2.3.6.1.1 Ethernet

Ethernet communication is established between packages utilizing the ethernet switch in the IOP. The IOP, FSAP, IPSU, SSC and PI hardware are connected with each other and ISS via the switch. Several functions are accomplished over ethernet, including:

- Command and control of the FSAP and IPSU
- Interprocess communication between the FSAP and IPSU, and between the FSAP processors
- Transmittal of PI hardware health and status acquired by the FSAP
- Data file transfer, including software upgrades, video, and science data, between the IOP and FSAP, IPSU, SSC, and PI hardware
- Time synchronization

In addition, the HRDL board is connected to the IOP via the ethernet switch. Data from the IOP is transmitted to ISS for onboard use or downlinking via the ethernet switch and HRDL boards.

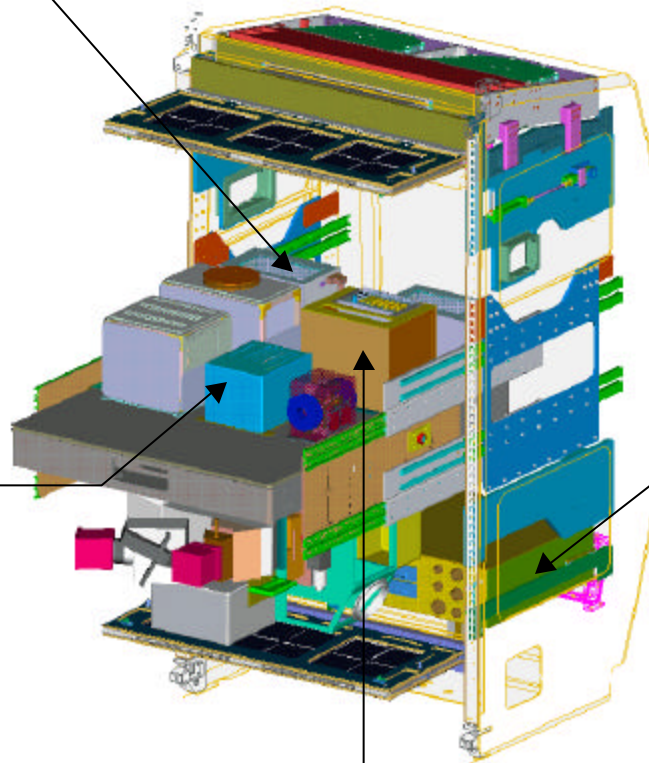
Finally, the rack ethernet is converted to fiber and routed to the SAR. This allows access to the SAR's ethernet subnet.

*The following figures shows the FIR avionics subsystems.*

## FCF FIR Data Acquisition Functions

### IPSUs

- Two Independent Image Processors
- Digital Camera Ready
- COTS Compact PCI Bus Technology
- Hard Drives (Qty. 4)
- Motion Control for APT/Focus/Zoom
- Ethernet / Serial Communications



### DCMs (not shown)

- Motion Controller
- 486DX-Based Single-Board Computer
- Servo Motor Controllers/Drivers
- Stepper Motor Controller/Drivers
- CAN Bus Controller

### FSAP and PI-FSAP

- Real Time Data Acquisition and Control
- Color Camera Support
- COTS Compact PCI Bus Technology
- Hard Drives (Qty. 2)
- Ethernet / Serial Communications
- Digital and Analog I/O
- Motion Control
- Ready to Accommodate Science Specific Hardware

### IOP

- HRDL, MRDL, 1553B Station Interface
- Ethernet, 1553, Serial Intrarack Communications
- PFM Video Interface (CVIT)
- Supervisory Control & Data Acquisition
- Removable Hard Drives (Qty. 2)
- Time Server and interface to ISS timing
- Health and status collection

### **B.2.3.6.1.2 Avionics CAN Bus**

The Avionics Controller Area Network (CAN) Bus is utilized to perform package commanding, control, and health and status monitoring.

The FSAP has the capability of controlling the following packages using the Avionics CAN Bus:

- Illumination packages, including the white light, laser diode, and Nd:YAG laser packages
- Diagnostic packages, including the DCM, color camera IAM, Translation Stage, and Gimbaled Mirror

The IPSU has the capability of controlling the following packages using the Avionics CAN Bus:

- Diagnostic packages, including the DCM, macro/micro IAMs, Translation Stage, and Gimbaled Mirror

The IOP performs health and status monitoring of the following packages utilizing the Avionics CAN Bus:

- Avionics packages, including the FSAP and IPSU
- Illumination packages, including the white light, laser diode, and Nd:YAG laser packages
- Diagnostic packages, including the DCM, color camera IAM, Translation Stage, and Gimbaled Mirror

### **B.2.3.6.1.3 ECS Can Bus**

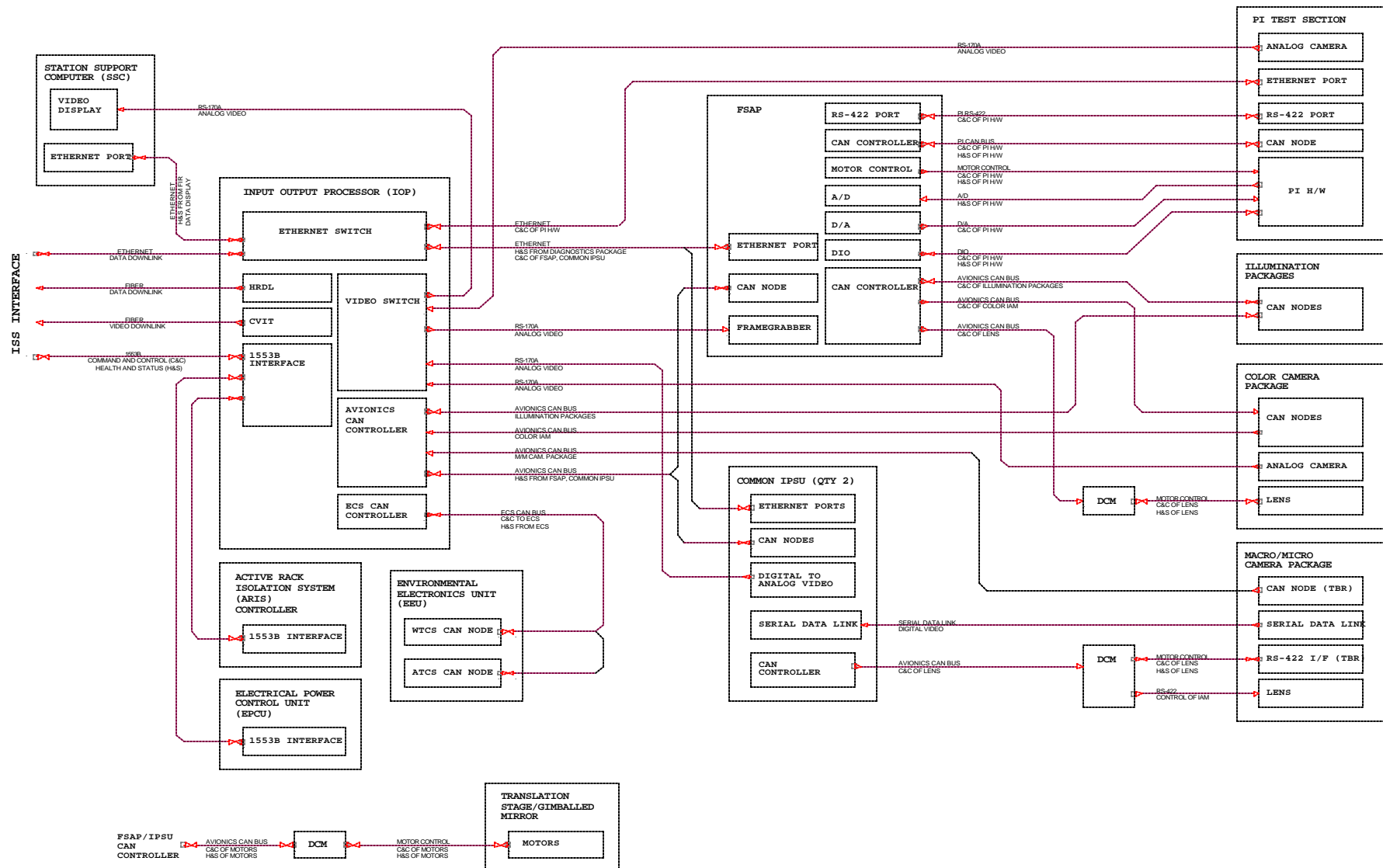
The Environmental Control System (ECS) CAN Bus is utilized to provide commanding, control, data acquisition, and health and status monitoring of the ECS packages. The IOP sends control signals to the ECS via the ECS CAN Bus to set blower speed, perform water valve control, etc. In addition, health and status parameters including temperatures, voltages, water flow rates, fan speeds, etc. are sent to the IOP via the ECS CAN Bus. The ECS CAN Bus is also used to communicate with the Atmospheric Monitoring Assembly (AMA). Humidity and temperature measurements are reported back to the IOP from the AMA.

### **B.2.3.6.1.4 PI CAN Bus**

The PI CAN Bus is utilized to control PI hardware. The controller is located in the FSAP and controls PI hardware operation and can acquire some of the PI hardware health and status.

*The facing figure shows the CDMS interface block diagram detailing the FIR CDMS subsystems.*

## Fluids Integrated Rack CDMS Block Diagram



### **B.2.3.6.2 Video Distribution**

Analog and digital video are distributed from cameras in the FIR to avionics located in the FIR or SAR. Each is discussed below.

#### **B.2.3.6.2.1 Analog Video Distribution**

Analog video transmission in the FIR is composite video and uses the differential RS-170A standard (except for the analog video output to the SSC). The video switch in the IOP accepts a variety of analog video sources including:

- Facility provided color camera
- PI specific analog camera(s)
- Analog video signal from an IPSU(s), which is converted from the digitally acquired video signal
- Video signal from the fiber optic receiver in the IOP

The video is routed to any of the following destinations:

- FSAP for digitization, processing, and storage
- PI for storage on PI provided tape drives
- CVIT in the IOP for conversion to PFM video on fiber for sending to ISS video storage or downlinking
- Analog video fiber optic transmitter in the IOP for transmittal to the SAR for viewing on a monitor
- To the SSC for astronaut viewing

#### **B.2.3.6.2.2 Digital Video Distribution**

Digital video is transmitted from cameras to IPSUs via the Serial Data Link. Cameras on the FIR optics bench output their data on single fibers. These fibers connect to one of two connectors with twelve possible inputs on the front of the optics bench. One connector routes the video data to the IPSUs located on the rear of the optics bench. The other connector routes the video data to IPSUs located in the SAR

#### **B.2.3.6.3 Time synchronization**

Time synchronization is performed over the 1553B connection between the IOP and ISS, and ethernet connection between the IOP and FSAP, IPSU, and PI hardware. The IOP synchronizes its internal clock to the ISS timing signal delivered to it via 1553B. The IOP performs time server functions. The FSAP, IPSU, and PI hardware synchronize their internal clocks to the IOP clock via ethernet and appropriate software protocols.

#### **B.2.3.6.4 Sync Bus**

The Sync bus is routed throughout the rack to synchronize package operation together, e.g. strobing of an illumination package with respect to camera shuttering. The IOP generates a frequency programmable sync signal consisting of a square wave.

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#### **B.2.3.6.5 Data Storage**

Data storage is accomplished in several of the avionics packages. Image data is acquired and stored in the IPSU. Image and science data are acquired and stored in the FSAP. Both the IPSU and FSAP contain disk drives for this storage. Data is temporarily stored on each until it is sent to the IOP, where it is stored on removable hard drives. This data can be downlinked or transported to earth on the drives depending upon ISS resources.

#### **B.2.3.6.6 PI Interfaces**

Several PI interfaces exist, some of which have been discussed already. The following are services that are provided to the PI. Quantity of channels and capabilities can be found in the FSAP section of this document.

- Analog to digital conversion (A/D)
- Digital to analog conversion (D/A)
- Digital inputs and outputs (DIO)
- Motor control
- Ethernet
- Sync Bus
- PI and Avionics CAN Bus
- Analog Video inputs and outputs

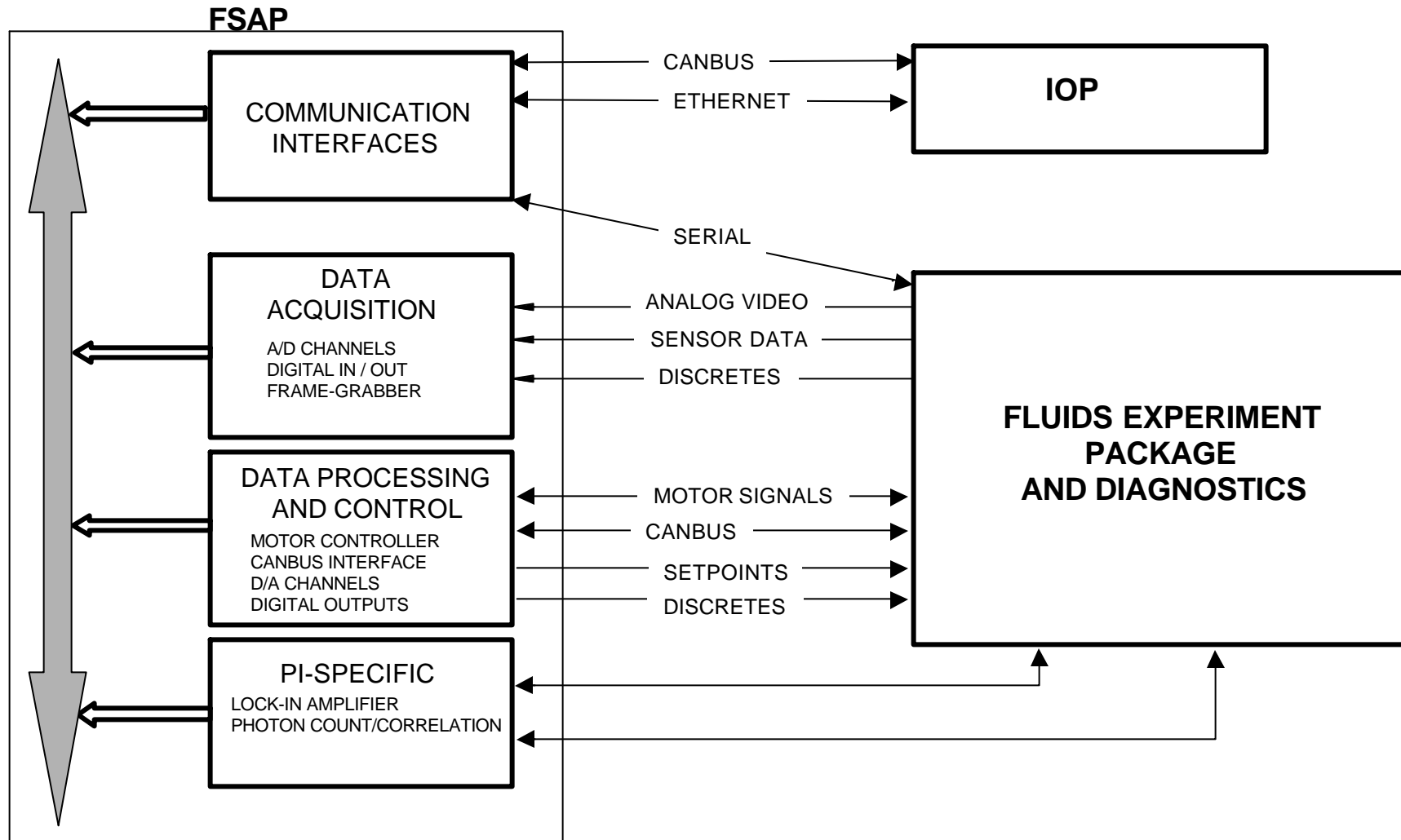
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### B.2.3.7 Fluids Science Avionics Package (FSAP)

The Fluids Science Avionics Package (FSAP) is a flexible, multi-purpose data acquisition and control system that is used to provide the capability to interact effectively with a wide range of fluids experiments. The FSAP consists of two enclosures: the main section and the PI section. The **FSAP Main Section** provides a standard set of analog and digital I/O, motion controllers, analog video acquisition, data storage, and communication connectivity. It is flown up with the rack and stays on-orbit for use by PI experiments. The **FSAP PI Section** (also known as PI-FSAP) provides an enclosure that consists of a microprocessor, communication interfaces, and available card slots for PI use. The PI has the ability to configure the FSAP PI Section on the ground with a set of science-specific circuit boards, and then fly it for use with the experiment.

*The components that comprise the FSAP are shown in the following figure.*

## FSAP System Interface Block Diagram



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### B.2.3.7.1 FSAP Main Section – Capabilities

The following items are used by the FSAP Main Section:

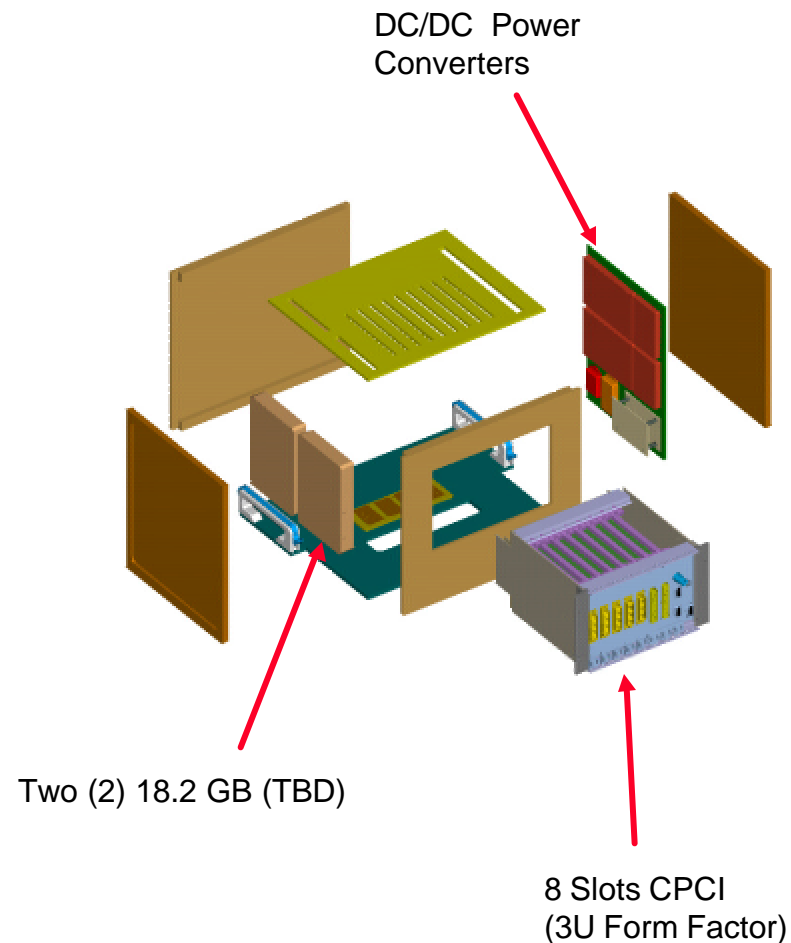
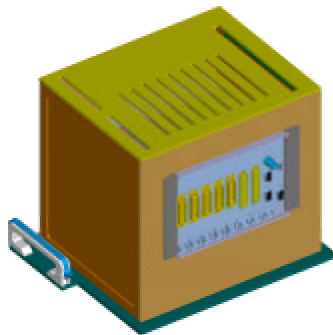
- **Analog Frame-grabber** capable of acquiring RS-170A analog video at a rate of 30 frames per second
- 48 channels of optically isolated **digital I/O** that consists of 24 input and 24 output channels
- 16 differential **A/D channels** with 16-bit resolution, programmable gain, and a sampling rate of 67 kHz (total for all channels)
- 4 differential **A/D channels** with 16-bit resolution, programmable gain, and a maximum sampling rate of 100 kHz
- 8 differential **D/A channels** with 16-bit resolution, with a 2k update buffer, and a maximum update rate of 100 kHz
- 16 **thermistor channels** with an excitation current source of 1mA and thermistor range up to 5kOhms
- Two axes of motion control for **stepper motors** running in full, half, and microstep configurations with stepper output rates up to 240k pulses per second
- Two axes of motion control for **servo motors** with a servo output of  $\pm 5$  VDC and a resolution of 12 bits
- **Automated position and tracking** (APT) capability utilizing the CAN controller and DCM

*A block diagram and concept of the FSAP Main Section are shown in the following figures as well as the PI-FSAP concept..*

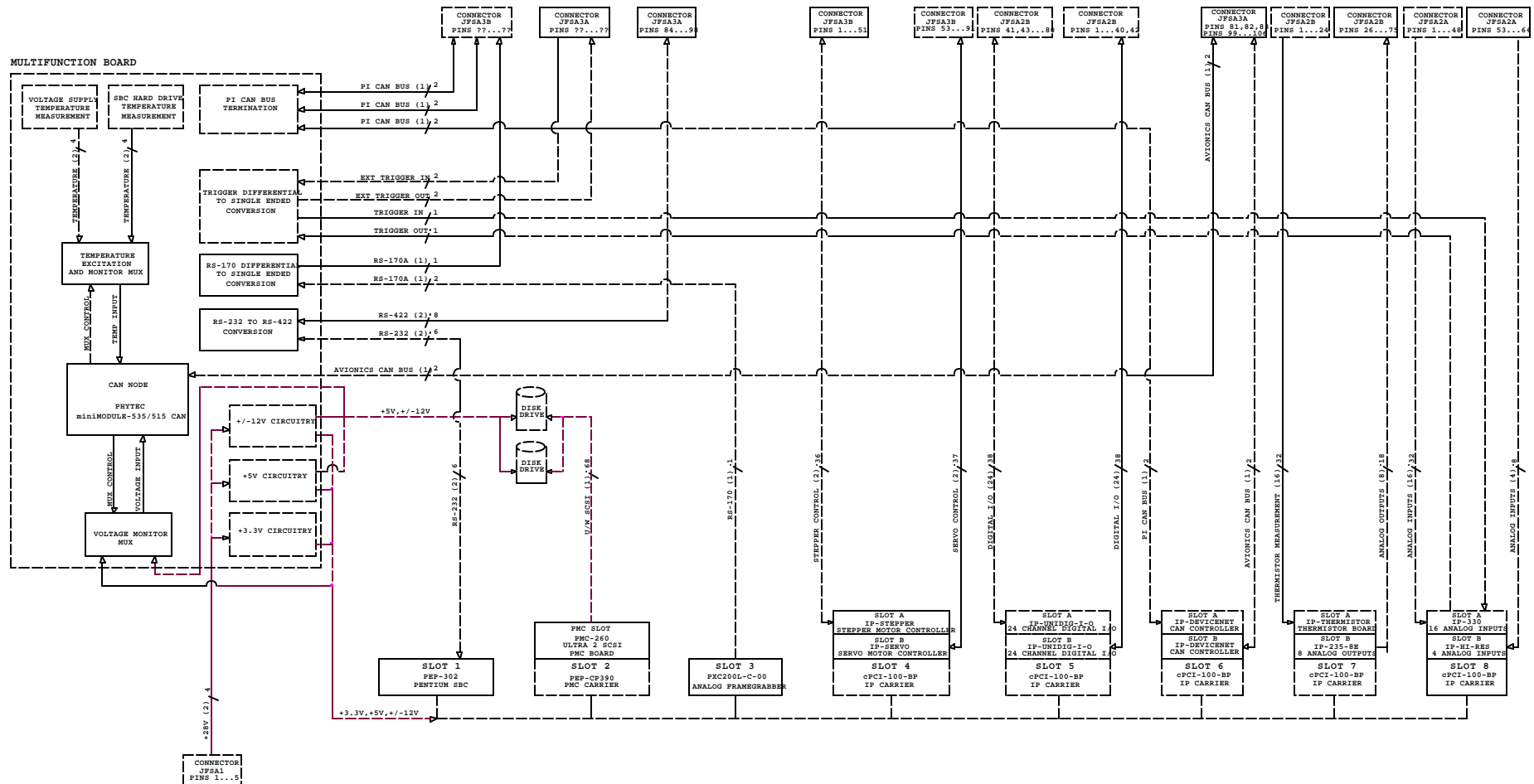
## FIR FSAP

### Main Section cPCI Slots

1. Single Board Computer w/Serial I/O and Ethernet
2. Ultra-wide SCSI Controller
3. Analog Video Frame-grabber
4. Industry Pack Carrier Board  
Motion Control, 2-channel Stepper I/F  
Motion Control, 2-channel Servo I/F
5. Industry Pack Carrier Board  
24 Channels Digital I/O  
24 Channels Digital I/O
6. Industry Pack Carrier Board  
CANbus Interface Module  
CANbus Interface Module
7. Industry Pack Carrier Board:  
D/A Converter (16 bits, 8 channels)  
IP-Thermistor (16 Channel)
8. Industry Pack Carrier Board  
A/D Converter (16 bits, 16 channels)  
A/D Converter (16 bits, 4 channels)



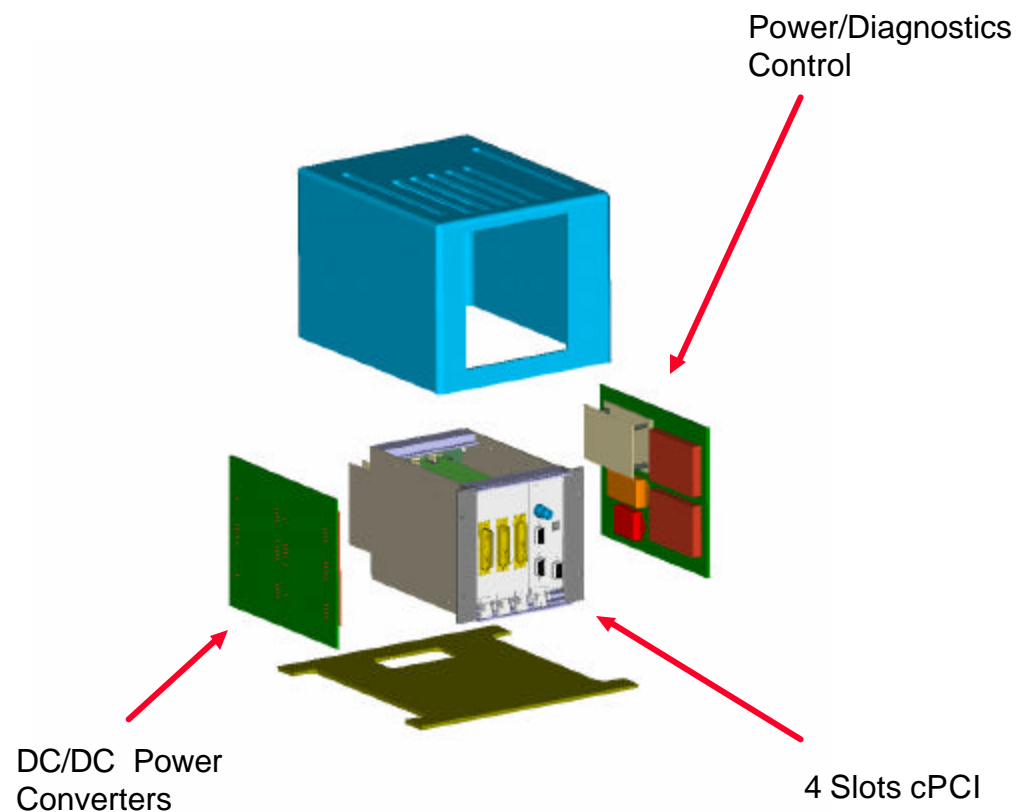
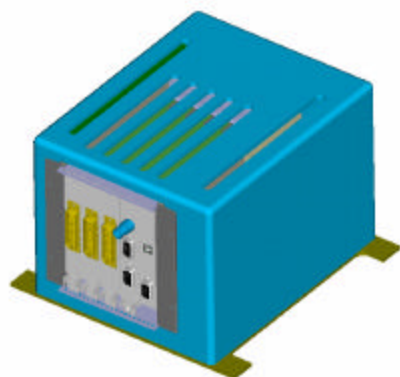
## FIR FSAP Main Section Block Diagram



## FIR FSAP- PI Section

### PI Section cPCI Slots

1. Single Board Computer w/ethernet
2. Reserved – PI-specific
3. Reserved – PI-specific
4. Reserved – PI-specific



### B.2.3.8 FIR Software

The FCF FIR CDMS and Control software supports both facility diagnostics and specific experiment hardware.

#### FIR Software Description

The FIR software is designed to easily interface specific science diagnostics and to work in concert with all FIR resources.

A **multitasking operating system**, VxWorks, will be employed to meet the real-time requirements for data acquisition and control. Real-time, deterministic response is a design goal.

The **software system** will be capable of upgrades using the command uplink channel.

**FSAP software** controls motors, lasers, lighting, and other components that relate to science diagnostics. It will also collect and archive science data. The FSAP communicates with other systems for data offloading as well as for command and control. A PI FSAP is supplied to host any experiment-specific hardware beyond what the FIR provided to the FSAP hosts.

**IPSU software systems** are designed to control cameras and are responsible for the collection of image data from their respective cameras.

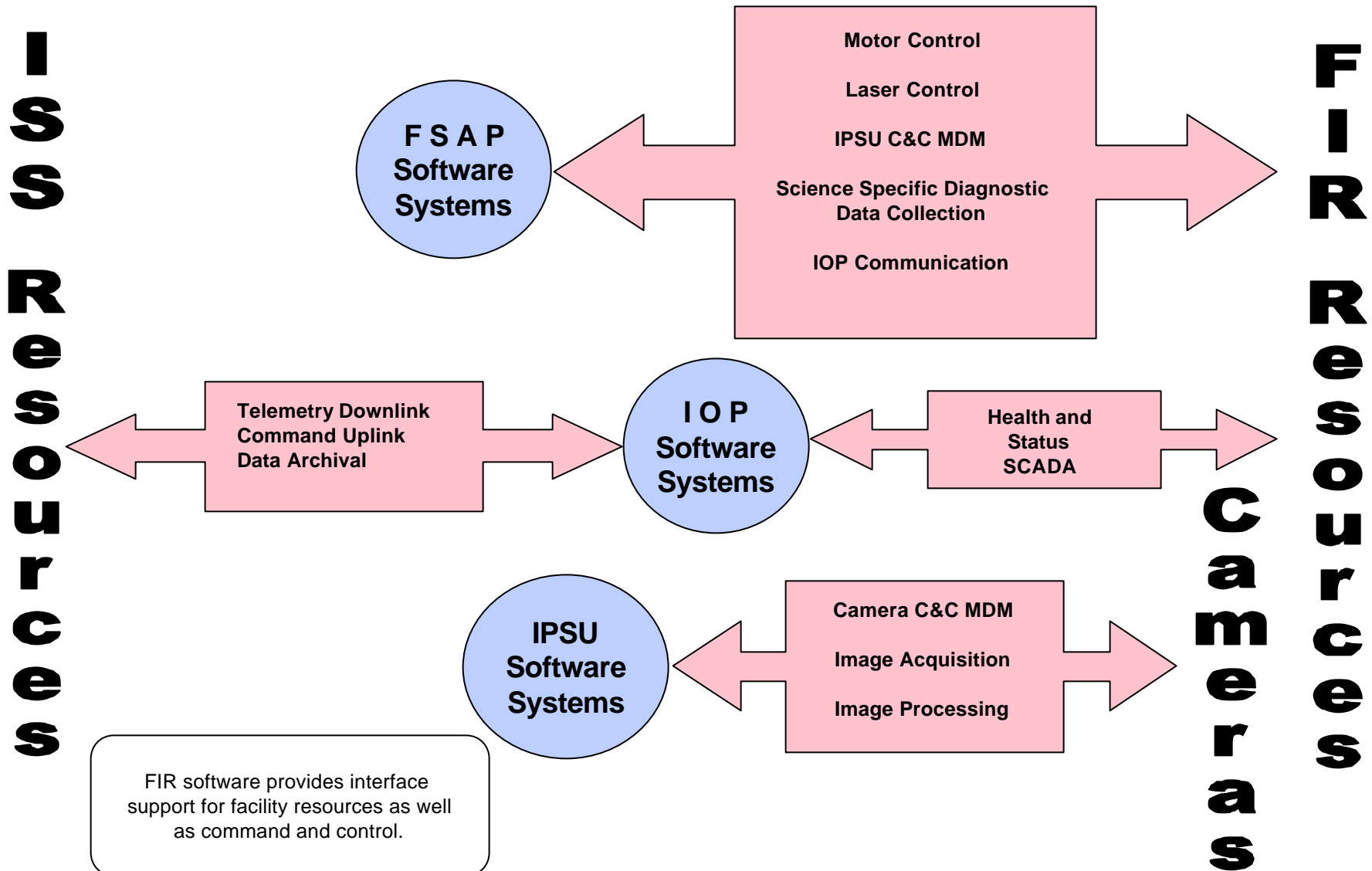
**IOP software systems** are designed for Supervisory Control and Data Acquisition (SCADA). This system interfaces both the FIR and the ISS resources. FIR resource interfaces provide health and status monitoring and some pre-experiment control. ISS interfaces provide for telemetry and science data downlink as well as command uplink.

#### Design Approach

The FIR software requirements and design are captured using Unified Modeling Language (UML). This approach provides a direct flow from the requirements definition to design to implementation. From any point of the process there is an upstream and a downstream link from the requirements to the code. The UML approach realizes the identification of common components of software, which promotes code re-use and in turn minimizes the complexity and the risk of software defects.

*The FIR software architecture is shown in the following figure.*

## FCF Software Architecture



### B.2.3.8.1 FIR Software Architecture

The FCF FIR software architecture distributes processing functions between several packages. FIR uses a client-server communication theme for inter-package communication.

### B.2.3.8.2 IOP Software

The IOP hardware and software are identical in the CIR, the FIR, and the SAR. Refer to the CIR section of this document for a complete description of the IOP software.

### B.2.3.8.3 Fluid Science Avionics Package (FSAP) Software

The Fluid Science Avionics Package (FSAP), part of FCF FIR, controls diagnostic devices and acquires diagnostic data for science. Specific science devices are controlled by FSAP software from several fixed device interfaces of the package. FIR software provides an interface to each device so that experiment-specific software can focus on science and not on the devices controllers. The control and acquisition components of the FSAP are as follows:

- 48 Discrete I/O Channels
- 16 A/D Channels, 16-bits each
- 4 A/D Channels, 16-bits Simultaneous Acquisition
- 8 DAC Channels, 16-bits each
- 2 Stepper Axes
- 2 Servo Axes
- 16 Thermistor Channels, 12-bits each
- Color Analog Frame-grabber
- Interface to FCF CAN Network
- Separate CAN Interface for exclusive PI use
- Ethernet Controller for FCF Local Area Network (LAN)

The experiment software interface to these devices is a C++ API, which allows the experiment software to follow the object-oriented model of the FIR software architecture.

#### B.2.3.8.3.1 FSAP Software Features

Built-in features of each device interface are provided by FIR.

##### Discrete Input Channels

The following items apply to the Discrete Input Channels:

- The **three methods** of detecting a state change of an input are as follows:
  - Interrupt level notification.
  - Polling based on a background timer.
  - Directly reads
- A **de-bounce time** is configurable for each input

##### Discrete Output Channels

The following items apply to the Discrete Output Channels:

- Output can be set to a specific state
- Output can be inverted without regard to its current state

*The FIR software architecture is shown in the following figure.*



### **Analog-to-Digital Converters**

The following items apply to the Analog-to-Digital Converters:

- Single sample reads from a single channel are available
- Continuous sample reads, based on time, provide the experiment software with “filled” buffers for processing and/or storage
- Interrupt level access for each sample, even in Continuous mode
- Engineering units conversion

### **Digital-to-Analog Converters**

The following items apply to the Digital-to-Analog Converters:

- Direct channel writes
- Ramping to a set-point, based on time and desired value
- Open loop profiling
- Engineering units conversion

### **Motion Controllers (Stepper and Servo)**

The following items apply to the Motion Controllers:

- Linear or Rotational motion control
- Interrupt feedback
- Hardware profiling

### **CAN Interface**

The following items apply to the CAN Interface:

- Interrupt level notification of incoming CAN messages
- Software and hardware filtering of message IDs

### **Thermistor Interface**

The following items apply to the Thermistor Interface:

- Device is very similar to an A/D. Its channel interface is identical to that of an A/D
- Single sample reads from a single channel are available
- Continuous sample reads, based on time, that provide the experiment software with “filled” buffers for processing and/or storage
- Interrupt level access for each sample, even in Continuous mode
- Engineering units conversion

### **Color Frame-grabber**

The following items apply to the Color Frame-grabber:

- Analog Signal Frame-grabber, maximum of 30 frames per second
- Black and white or color signals are supported
- Single grab support
- Continuous grab support to the same destination, such as video memory
- Consecutive grab support to different locations
- Real-time disk archiving is available
- Real-time hardware compression is available to minimize stress on resources when science is non-critical
- Real-time lossless software compression is optional to maximize disk utilization of optimal science data
- Decimation of frames is available

The built-in features of each device interface are provided by FIR.

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#### **B.2.3.8.4 PI-FSAP Software**

A second Fluid Science Avionics Package (FSAP) is provided in FIR in order to host additional computer hardware devices that are not supplied in the previously described FSAP. The PI-FSAP consists of a single board computer that is identical to the FIR FSAP. Common software allows the PI software to expand and to share software that has already been designed.

Any additional hardware that is not supported must have its own support software. FIR abstract interfaces are recommended as a starting point for common hardware and software functionality. For example, a different A/D board should start with the abstract A/D interface as defined by FSAP software.

##### **FSAP-to-FSAP Interface**

The two FSAPs can communicate via the Ethernet, which is a latency filled method of communication. The two FSAP systems may require fast response communication to properly control an experiment. The FIR FSAP has a CAN controller that has no other devices attached and is provided for exclusive PI devices. A connection to the PI-FSAP would provide a low latency connection between the two.

#### **B.2.3.8.5 DCM and Common IPSU Software**

The DCM and Common IPSU hardware and software are identical in CIR, FIR, and SAR. The FCF Main Body has a description of the IPSU and DCM software.

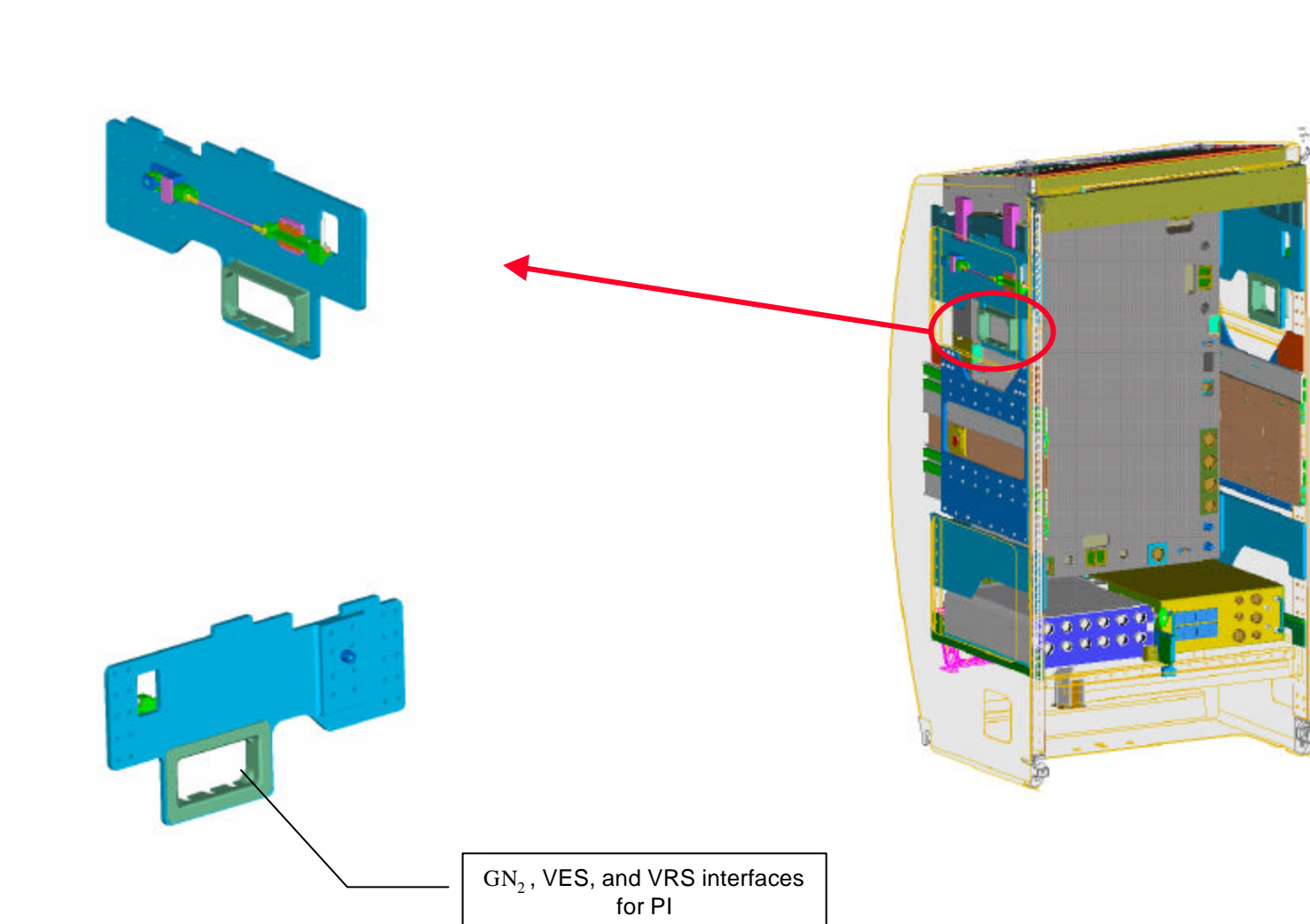
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### **B.2.3.9 Gas Interface System (GIS)**

The Gas Interface System (GIS) provides the FIR and experiments access to ISS Gaseous Nitrogen, Vacuum Resource, and Vacuum Exhaust services. The FIR has an independent GIS to facilitate distributed access. The GIS interface panel provides a crew-accessible panel that allows the FIR experiments to access the ISS resources. This arrangement facilitates a variety of configurations optimizing use of the ISS Gaseous Nitrogen and Vacuum Exhaust services.

*An overview of the FIR Gas Interface System (GIS) is shown in following figure.*

## FCF FIR Gas Interface Panel (GIP)



### B.2.3.9.1 Description

The FIR GIS interfaces with the Space Station gas services at the Utility Interface Panel (UIP). These services are routed to the Rack Utility Panel (RUP) using ARIS provided flexible umbilicals.

The Fluids Element and Experiment interface with the GIS is at the Gas Interface Panel (GIP). The GIP is mounted on the left side wall of the FIR. The GIP contains one quick-disconnect (QD) each for GN<sub>2</sub>, Vacuum Resource, and Vacuum Exhaust services. Flexible umbilicals interconnect all hardware elements with the GIP.

The GN<sub>2</sub> line contains a manually operated shutoff valve to provide rack level isolation. The Space Station controls rack level access to the Vacuum Resource and Vacuum Exhaust systems with isolation valves in the standoffs.

Pressure regulation, flow control and exhaust gas processing functions are allocated to the FIR hardware elements interfacing with the GIS.

Station provided connectors will be used for the interfaces at the UIP and the RUP.

For pressurized systems, the hardware is designed to comply with specific requirements other than fault tolerance. It must meet fracture control requirements and factors of safety listed in NSTS 1700.7, its addendum, MIL-STD-1522A, and NASA-STD-5003. This approach is generally not advisable for items that change configuration on-orbit since the original ground verification only applies to unmodified hardware. The FIR will need to demonstrate that the flexible umbilicals, if under pressure, will not break free and flail about.

The PI will also have to verify that what is being vented complies with the acceptable materials list and is compatible with the station hardware. The PI hardware that interfaces with the Vacuum Exhaust System (VES) is limited to 40 PSIA. If the pressure is expected to be greater, the PI must provide a pressure regulator.

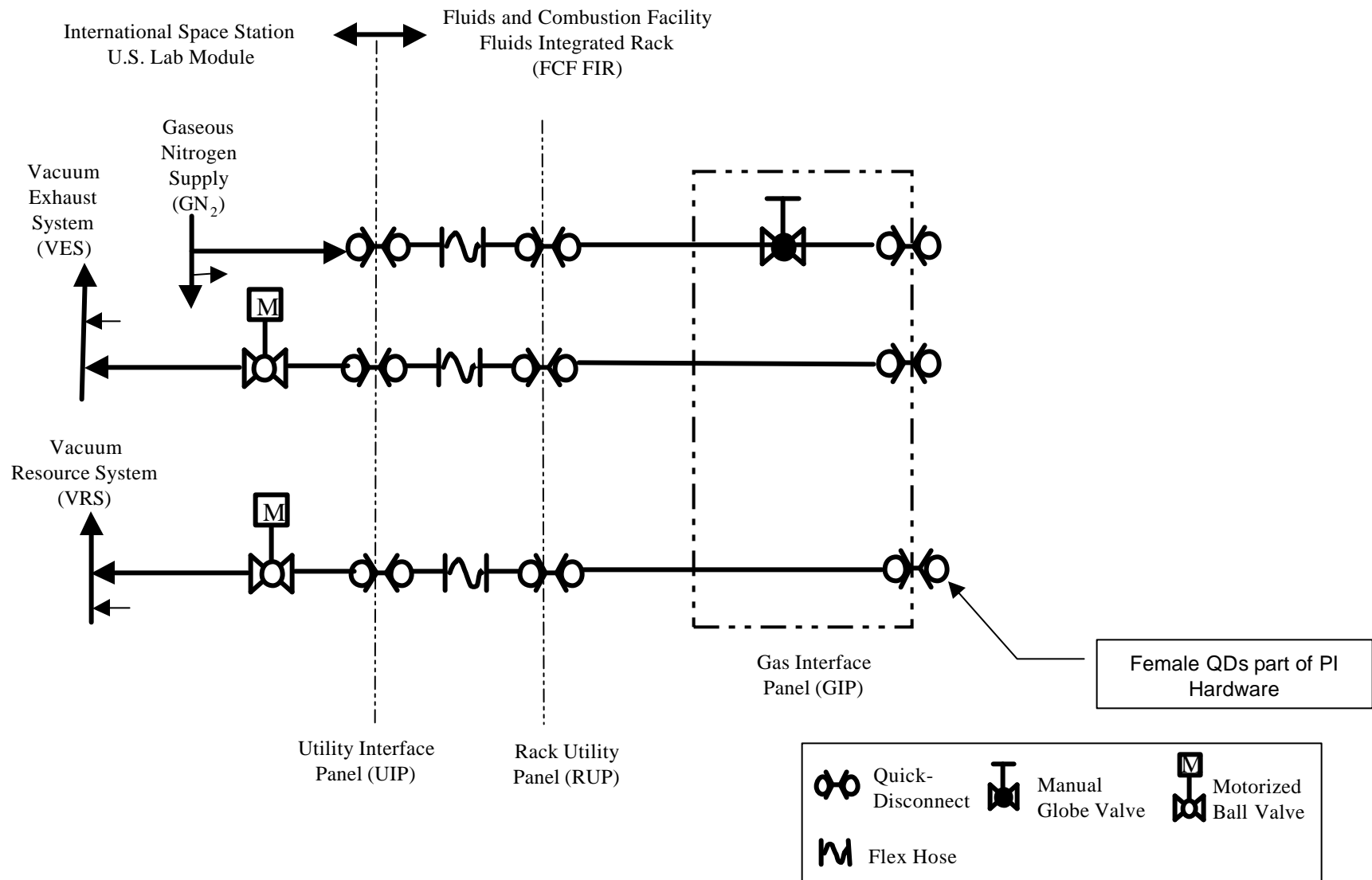
### B.2.3.10 Atmospheric Monitor Assembly

FIR/SAR will provide an atmospheric monitoring unit which has the following features:

- Measures pressure, relative humidity and temperature
- Pressure Range:  $\pm 0.15$  hPa (500-1100 hPa)
- Temperature:  $\pm 0.9$  °F (-40 to 140 °F),  $\pm 0.36$  °F @ 68 °F
- Humidity:  $\pm 2\%$  RH (0-90% RH)
- Communicate via CAN
- The location of the AMA in the rack is TBD.

*A schematic of the Gas Interface System (GIS) is shown in the following figure.*

## Gas Interface System Schematic



## B.2.4 FIR Metrics

### **FIR Mass Summary**

The following figure details the estimated mass of each FIR subsystem. The table lists all of the subsystems that will be needed for on-orbit operation as well as the subsystems that will be installed for launch. Additional information can be found in the *FCF Mass Properties Report No.1* (FCF-RPT-0061).

All of the diagnostics and image processing packages will be stowed in foam lined re-supply lockers for launch. This will minimize environmental testing of the packages which will reduce development costs and enable the project to use COTS for many of these components. To minimize crew time for the installment and reconfiguration, these components have an integral quick latch mechanism that allows for easy installation and removal.

*The following figure show the FIR Mass Summary for launch and on-orbit configurations.*

## FCF FIR Mass Estimates for Launch and On-orbit Configurations

FIR Mass Summary

	Assembly	Base Mass (Kg)	Percent of Total	Installed During Launch ?	Installed During Operation?
FIR ELEMENT	Optics Bench Assembly (includes optics bench, Support Plates, and Seals)	141.87	17.86%	Y	Y
	Cameras & IAMS (includes High frame rate camera)	10.97	1.38%	N	Y
	Translation Stage	5.17	0.65%	N	Y
	Lasers (Nd: Yag & Laser Diodes)	10.33	1.30%	N	Y
	Illumination (Dual White light)	4.49	0.57%	N	Y
	Lens Assembly (2 macro lens, color lens, hi-mag lens)	4.70	0.59%	N	Y
	Gimballed Mirror	4.54	0.57%	N	Y
	COLLIMATOR (10mm IQty 21 and 25 mm)	1.00	0.13%	N	Y
	Calibration equipment	2.27	0.29%	N	Y
	MOBILE FANS (Fan Post)	0.68	0.09%	N	Y
	Atmospheric Monitor Assembly	2.30	0.29%	N	Y
	PI-FSAP	12.32	1.55%	N	Y
	FSAP	15.83	1.99%	Y	Y
	MISC. (VRS Interface+ Camera mounts)	7.20	0.91%	Y	Y
COMMON HW	IPSUs (QTY. 2)	15.64	1.97%	Y	Y
	DCMs (QTY. 6)	13.02	1.64%	N	Y
	RACK DOORS	25.00	3.15%	Y	Y
	Pin Assemblies	5.95	0.75%	Y	Y
	Rack Misc Structures (center post & attachment HW)	10.57	1.33%	Y	Y
	I/O Processor	24.70	3.11%	Y	Y
	Stowage Items (hard drives for IOP)	4.44	0.56%	N	Y
	Slides (includes Rotational & Brake Assemblies)	48.54	6.11%	Y	Y
	Removable Latch for Diagnostics Mount	2.57	0.32%	N	Y
	ECS - Water Distribution & Control Assy	32.54	4.10%	Y	Y
	ECS-ACCUMULATOR ASSEMBLY (removed on-orbit)	1.80	0.23%	Y	N
	ECS - Air Thermal Control Assembly	44.64	5.62%	Y	Y
	Gas Interface System Assembly	16.23	2.04%	Y	Y
	Fire Detection & Supression Assy	2.47	0.31%	Y	Y
PI	Experiment Assembly -(Service Umbilical Set + ESSA)	6.48	0.82%	Y	Y
	PI Experiment Package	65.00	8.18%	N	Y
GFE	ARIS - Launch Condition*	61.06	7.68%	Y	Y
	ARIS - Additional On-Orbit Mass*	14.45	1.82%	N	Y
	Electrical Power Subsystem (EPS)-EPCU Assembly	48.53	6.11%	Y	Y
	EPS-EPCU Umbilicals	2.84	0.36%	Y	Y
	EPS-RMSA	0.64	0.08%	Y	Y
	Rack - Rack Assembly	111.90	14.08%	Y	Y
	Rack-Rack to Station I/F umbilical set (ARIS)	10.66	1.34%	N	Y
	SAMS Subsystem	1.23	0.16%	Y	Y
MANAGEMENT RESERVE					
GROSS TOTALS		794.55	100.00%		
Integrated Rack Limit		804.20			
Launch Configuration Base Estimate Mass		625.66	Margin		
Operating Configuration Base Estimate Mass		792.75	1.42%		

\*For additional details on mass estimates, see FCF-RPT-0061

### **B.2.4.1 FIR Electrical Power Distribution Subsystem**

#### **FIR Power Estimates**

Power estimates for the FIR subsystems are included in the Power Estimate Table. The estimates include the typical and maximum power consumed by each subsystem for both the 28 and 120 VDC supplies. Further details can be found in the *FIR Power Estimates Report* (FIR-RPT-0164), including total rack power estimates for each of the fluid physics basis experiments.

*The following figure shows the FIR  
maximum (worst-case) power estimates.*

## FIR Subsystems - Maximum Power Estimates

Hardware Assembly					Power Estimates					
					Maximum @ 28VDC AIR (Watts)	Maximum @ 28VDC WATER (Watts)	Maximum @ 120VDC AIR (Watts)	Maximum @ 120VDC WATER (Watts)		
Core Elements			IOP		160	0	0	0		
			ECS		191	0	3	0		
			ARIS		0	0	95	190		
			SAMS FF		2	0	0	0		
			SSC		39	0	0	0		
			AMA		2	0	0	0		
Fluids Elements	Science Diagnostic Packages	Avionics	FSAP	Main Section	140	0	0	0		
				PI Section (1)	100	0	0	0		
			Common IPSU (2 per)		300	0	0	0		
		Imaging Packages	Color Camera		40	0	0	0		
			Macro Camera		70	0	0	0		
			Micro Camera		70	0	0	0		
			HFR Camera		70	0	0	0		
			Translation Stage		31	0	0	0		
			Gimballed Mirrors		39	0	0	0		
		Illumination & Laser Light Packages	Dual White Light		394	0	0	0		
			Nd:YAG Laser		163	0	0	0		
			Dual Laser Diode		84	0	0	0		
		Cooling		Portable Fan		5	0	0	0	
		Science Specific Packages		PI	Air Cooled		500	0	0	0
					Water Cooled		0	0	0	0
		Subtotal			2300	0	98	190		
		Cable Losses (2%)			47	0	2	4		
		Subtotal			2347	0	100	194		
		EPCU			285					
		Total Power (Maximum)			2925					

\*For additional details on power estimates, see FIR-RPT-0164

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## Section B.3 FIR Utilization & Operations

## B.3 Utilization & Operations

The FIR features the capability to remove and replace different PI provided Experiment Packages (EPs). The PI experiment specific package(s) may consist of a single self-contained unit and/or several separate components. The PI hardware will typically be a unique design, but may re-use hardware and designs from previous experiments. A set of similar experiments investigating common phenomena and/or using similar diagnostics may permit the development of a “mini-facility” that can accommodate multiple PIs to significantly lower overall PI development costs. The experiment package will typically consist of the fluids test cell(s), precision optical diagnostic instrumentation (shearing interferometry, schlieren, surface profilometry, and so on) that interface with FIR services previously discussed, and any support equipment such as injection and mixing devices, motors, critical temperature hardware, magnetic field generation, and so on.

### B.3.1 Generic FIR Experiment Envelope

The FIR is capable of accommodating many different sized experiment packages. Its design is intended to be flexible enough to accommodate most anything within the physical dimensions from the front of the optics plate to the ISPR door. However, the ISS provides resource allocations to the FCF that put some limits as to what FIR can accommodate. In the future, it is foreseeable that the typical allocation for a PI may increase, the FIR is designed with this in mind. The following items describe a typical EP envelope:

- **Volume** - An average volume of approximately 65 to 90 liters for PI test cells and associated equipment will be provided, with test cell volumes of up to 10 cm × 10 cm × 10 cm (1 liter).

- **Mounting** - Precision mounting/locking of EPs with respect to the rack optical components. Optional on-orbit test cell replacement without replacing the entire EP.
- **Containment** - One level of containment is standard for the test cell with an Experiment Package (EP) that provides a second level. Hazardous fluids will require a third level, usually at the test cell, in order to meet safety requirements.
- **Fluids Handling** - Mixing, injection, and so on, as necessary to meet experiment requirements.
- **Environment Data Acquisition** - Thermocouples, thermistors, pressure transducers, and so on, are necessary to meet the experiment requirements.
- **Standard Interfaces** - Contain electrical, mechanical, and optical components, as necessary, to interact with standard rack interfaces for data acquisition, motor control, image acquisition, heat rejection, vent/vac, GN<sub>2</sub>, and cooling.
- **Heat Rejection** - A connection to the FIR water loop will be available to the EP. The water loop provides temperature control to within 1°C. Additional precision can be obtained using PI-provided thermoelectric coolers.

*The anticipated FIR Traffic Model for PI hardware, is shown in the following figure*

## GRC/MSD ISS Utilization Traffic Model

Rev. DCN-04	4/19/01	6/21/01	8/23/01	1/17/02	6/13/02	10/10/02	10/16/03	1/22/04	6/24/04	1/20/05	3/17/05		6/16/05	7/15/05	Oct. '05	Jan. '06	Apr. '06	July '06
FLIGHT	6A	7A.1 <sup>1</sup>	UF-1	UF-2	9A.1 <sup>1</sup>	12A.1	UF-3	UF-4 <sup>2</sup>	UF-5	17A	19A	HTV2 <sup>3</sup>	UF-7	UF-6	LF-?	LF-?	LF-?	LF-?
Facilities	ER <sup>1</sup> ARIS	ER <sup>4</sup> ARIS	MSG ARIS	ER <sup>3</sup> ARIS			CIR ARIS		FIR ARIS	ER <sup>7</sup> ARIS	ER <sup>6</sup> ARIS	LTMPF ARIS					SAR ARIS	
Combustion Science							D-DCE-2 MDCA-2		MDCA-3 MDCA-4 MDCA-1 MDCA-2	FEANICS-1 FEANICS-2 MDCA-3 MDCA-4			MGFA-1 FEANICS-1 FEANICS-2		MGFA-2	FEANICS-3 MGFA-1 MGFA-2	FEANICS-4	FEANICS-5 FEANICS-3 FEANICS-4
Commercial / International							DECLIC		CFCF-A <sup>1</sup>		CFCF-A <sup>1</sup>		CFCF-B <sup>1</sup>				CFCF-B <sup>1</sup>	Tarifa
Fluid Physics	PCS <sup>6</sup>			PCS					LMM-1 LMM-2 <sup>7</sup> LMM-1	LMM-3 Maxworthy (DECLIC)			LMM-2	LMM-4	LMM-3	LMM-5 LMM-4	GFM-1 LMM-6 LMM-5 Sangani SAR - GFM	LMM-6
Glovebox	PI			CSLM-2 <sup>5</sup>	CSLM-2				EGM				EGM			Marston		
Acceleration Measurement	MAMS ICU RTS-D1 RTS-D2 EE-ER <sup>2</sup> SE-PCS		RTS-MISO	EE-ER <sup>3</sup>			RTS-ASRR <sup>1</sup> SE-CIR CU ICU <sup>4</sup>		SE-FIR	EE-ER <sup>7</sup> EE-ER <sup>8</sup>		RTS-JTMPF					SE-SAR	

Initial FIR PIs

### Facility Acronyms:

ER - EXPRESS RACK  
DECLIC - Dispositif pour l'Etude de la Croissance et des Liquides Critiques  
MSG - Microgravity Science Glovebox  
MGBX - Middeck Glovebox  
CIR - Combustion Integrated Rack  
FIR - Fluids Integrated Rack  
SAR - Shared Accommodations Rack

### Legend:

	upmass	downmass
Combustion Science Investigation -	● / ●	○ / ○
Fluid Physics Investigation -	■ / ■	□ / □
Materials Science Investigation -	◆ / ◆	◇ / ◇
Acceleration Measurement Hardware -	▲ / ▲	▼ / ▼

NOTE: P/L's shown for planning purposes only will not have a solid color  
Rev. E-DCN-04 Assembly Sequence - CR #3178 RA

### FCF P/L Module Acronyms: (module traffic will be denoted by '●' Module Name '●')

MDCA - Multi-use Droplet Combustion Apparatus (P.L.: Williams, Shaw, Choi, Nayagam) - P/L denoted as "D-P/L acronym"  
FEANICS - Flow Enclosure Accommodating Novel Investigations in Combustion of Solids (P.L.: T'ien, Kashiwagi, Fernandez-Pello, Wichman, Ronney)  
MGFA - Multi-use Gaseous Fuel Apparatus (P.L.: Hermanson, Law, Cheng, Axelbaum)  
LMM - Light Microscopy Module (P.L.: Wayner, Chaikin, Weitz, Yodh, Gast, Clark)  
GFM - Granular Flow Module (P.L.: Jenkins, Louge)  
CFCF - Commercial Fluids/Combustion Facility modules

### Notes:

- 1) Formal launch/utilization agreements with SPD are in work.
- 2) Not an MPLM Flight
- 3) SpaceHab Flight not an MPLM Flight
- 4) SAMS-II ICU to return on first available flight after checkout of the SAMS-II CU.
- 5) CSLM-2 has Sample Processing Units (SPU) returning on 9A.1 (6/02) and 11A (5/02).
- 6) PCS has data disks returning on 7A.1 (6/01), 8A (10/01) and UF-2 (1/02).
- 7) LMM-2 launches in the middeck on 20A (9/04)

GRC Microgravity Science Division Chief: /s/ Jack Salzman - 04/07/00

### B.3.1.1 Initial Principal Investigators for FIR

To evaluate FIRs ability to accommodate potential experiment requirements, the initial Principal Investigator (PI) proposals have been analyzed and concepts developed to assess compatibility with hardware design. Basis Experiment compatibility with the described FIR concept is described in detail in the *FIR Basis Experiment Concepting Summary Report* (FIR-DOC-040).

The following PIs have been identified as the potential first payloads for the FIR. These experiments and the Basis Experiments that are defined in the SRED will be used to evaluate overall FIR science requirement compliance. This overview is based on the best information available but should be regarded as information only. This section will be updated as experiment Teams are assigned and/or better information becomes available.

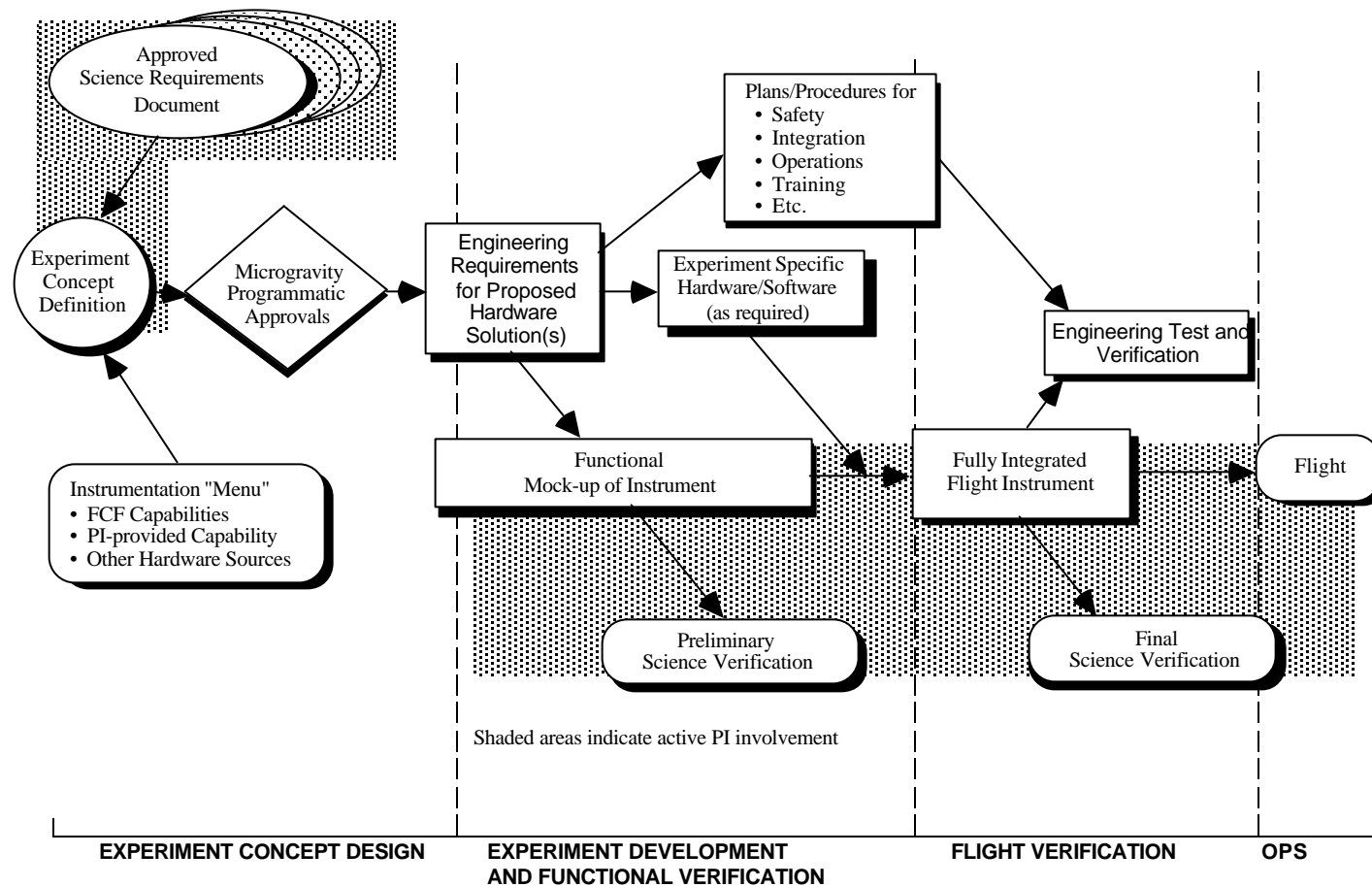
The following experiments have been identified as candidates for the FIR:

- **Wayner** - Constrained Vapor Bubble (LMM)
- **Chaiken** - Physics of Hard Spheres - 2 (LMM)
- **Weitz** - Physics of Colloids in Space - 2 (LMM)
- **Yodh** - Colloidal Assembly (LMM)
- **Jenkins** - Segregation in Binary mixtures of Inelastic Spheres
- **Louge** - Gas Particle Interaction
- **Sangani** - Behavior of Rapidly Sheared Bubbly Suspensions
- **Garoff** - Microscale Hydrodynamics Near Moving Contact Lines
- **Durian** - Foam Optics and Mechanics (FOAM)
- **Dhir** - Mechanistic Study of Nucleate Boiling Heat Transfer under Microgravity Conditions

These experiments are summarized within this section. A potential concept for each experiment has been identified within the FIR to aid in evaluation of accommodations and compatibility.

*The evolution of the requirements for the Experiment hardware is shown in the following figure.*

## Evolution of Requirements to FIR Experiment Flight Hardware



### B.3.1.2 Conceptual FIR Experiment Integration

#### Light Microscopy Module (LMM)

The Light Microscopy Module (LMM) for the FCF FIR is designed to meet the needs of many fluids and colloid experiments, thus maximizing the opportunity of each microscopy PI to use existing hardware. The LMM package combines a full featured research imaging light microscope with powerful laser diagnostics, creating a one-of-a-kind, state-of-the-art microscopic fluids research instrument. Detailed information is provide in *Light Microscopy Module (LMM) Baseline Concept Document* (LMM-DOC-0005).

The imaging techniques of high-resolution color video microscopy, bright field, dark field, phase contrast, differential interference contrast (DIC), fluorescence, and confocal microscopy are combined in a single configuration with dynamic and static light scattering techniques. This suite of measurements allows a very broad characterization of fluids, colloids, and two-phase media. Sample manipulation techniques also integrated with the diagnostics are single-trap scanning optical tweezers.

The LMM accepts a cell assembly from a PI team which conforms to a generic interface on the LMM sample stage. Electrical leads from the sample tray plug into the electrical control interface. This allows PI manipulation of the sample heating or cooling, as well as PI-specific temperature and pressure sensors within the sample cells. Various design elements are integrated within the LMM concept. The elements are described in the body of this document, separated into the disciplines of optical diagnostics, mechanical, and electrical systems.

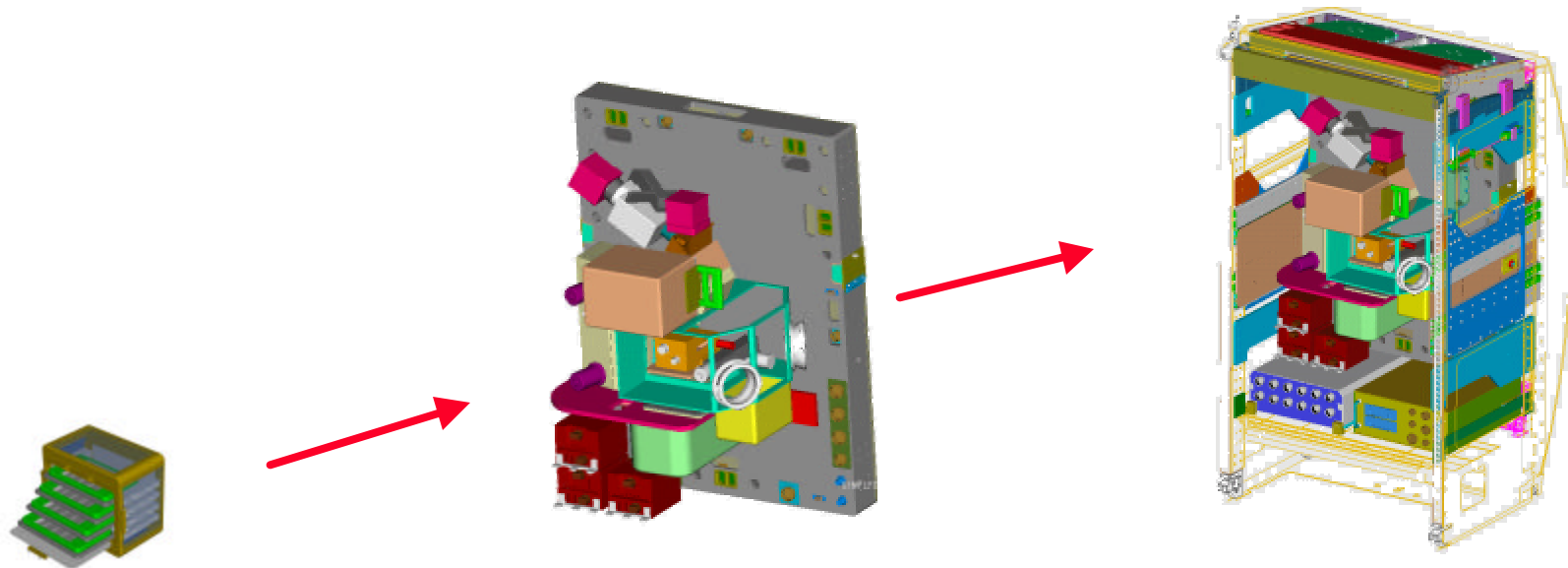
#### LMM Experiments

The LMM concept is designed to provide accommodations for the initial four fluids experiments already selected for flight on the FCF FIR. FIR-DOC-040 summarizes the current engineering interpretation requirements for the FIR/LMM.

Requirements are derived from the Science Requirements Documents (SRDs) of PHaSE-2 (Physics of Hard Spheres Experiment-2), PCS-2 (Physics of Colloids in Space-2), CVB (Constrained Vapor Bubble), and Colloidal Assembly in Entropically-driven Low-volume Fraction Binary Particle Suspensions along with supplemental inputs from the Project Scientists and lead personnel of the “first four” Principal Investigator (PI) experiments manifest on FIR. These experiments, along with the various measurements or features known to be of importance to each particular PI, are listed below and are met by this LMM design concept.

*An display of the LMM integrated into the FIR Rack  
is shown in the following figure.*

## Integrated FCF FIR/LMM Concept



### PI-specific Hardware

- Samples with supporting hardware
- Specific Diagnostics
- Specific Imaging

### Light Microscopy Module (LMM)

- Test Specific Module
- Science Infrastructure (hardware/software) items that uniquely meet the needs of the P-2, Yodh, and Wayner PIs
- Unique Diagnostics
- Specialized Imaging
- Fluid Containment

### Fluids Integrated Rack (FIR)

- Power Supply
- Avionics/Control
- Common Illumination
- PI Integration Optics Bench
- Imaging and Frame-capture
- Fluid Diagnostics
- Environmental Control
- Data Processing
- Frangibles and Laser Light Containment

### **WEITZ / CHAIKIN: PCS-2 / PHaSE-2**

The following items apply to the Weitz/Chaikin PCS-2/PHaSE-2 experiment:

- Fiber DLS (Dynamic Light Scattering), SLS (Static Light Scattering), DWS (Diffusing Wave Spectroscopy)
- Bragg scattering via 2-D CCD array
- Color imaging
- Video microscopy, using the following imaging techniques:
  - Brightfield
  - Darkfield
  - Phase contrast
  - DIC
  - Fluorescence
  - Oil immersion
- Cell change-out, with  $\approx 240$  samples per cell assembly
  - Sample homogenization
  - Optical tweezers for trapping and microrheology
  - Confocal microscopy

### **YODH: *Colloidal Assembly in Entropically-driven Low-volume Fraction Binary Particle Suspensions***

The following items apply to this experiment:

- DLS, SLS, DWS
- Video microscopy
- Spectrophotometry

### **WAYNER: CVB**

The following items apply to this experiment:

- Video microscopy
- Thin film thickness measurements using interferometry
- Macroscopic view of bubble dimensions and location
- $\Delta T$  held with in  $1^\circ\text{C}$  ( $33.8^\circ\text{F}$ )
- Measure sample temperature and cell pressure

### **LMM Technical Description**

The FIR LMM will provide the necessary diagnostics hardware and interfaces to conduct colloid fluid physics experiments. The diagnostics equipment will consist of the following items:

- Imaging Packages
  - Digital b/w camera
  - 2 analog color cameras
  - Multiplexed analog video ports
- Illumination Packages
  - Halogen Light Source(s)
  - Hg Vapor Light Source
  - 532 nm doubled Nd: YAG laser
- Laser Light Scattering
- Laser tweezers, with 1064 nm Nd: YAG laser
- Spectrophotometer
- Confocal Imaging

In addition, the LMM will have the ability to be reconfigured to accommodate the various fluid experiments requiring the use of a high-power microscope. This will include the occasional removal of the microscope condenser dovetail assembly allowing the X-Y positioning stage to be lowered for larger sample cell placement.

Refer to the *LMM Baseline Concept Description* (BCD) (LMM-DOC-0005) for more information on the LMM.

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### **B.3.1.3 Granular Media**

#### **Microgravity Segregation in Binary Mixtures of Inelastic Spheres Driven by Velocity Fluctuation Gradients**

*Dr. James Jenkins, Dr. Michael Louge  
Cornell University*

#### **Gas Particle Interaction**

*Dr. Michael Louge  
Cornell University*

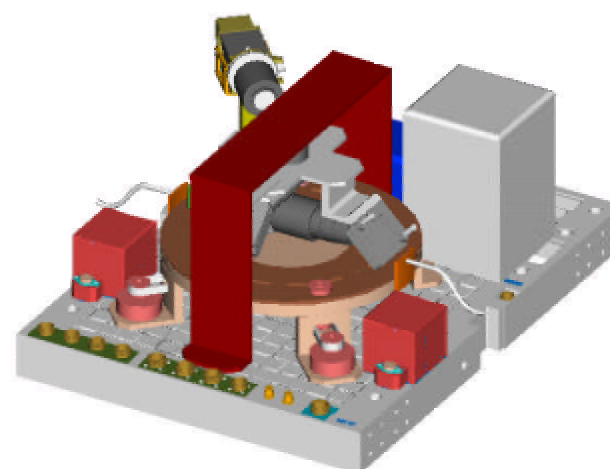
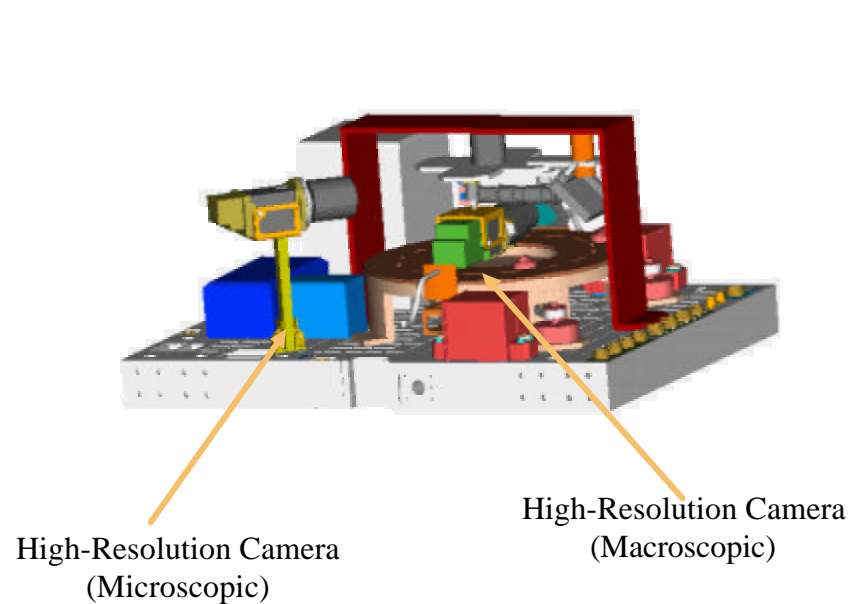
These experiments concern rapid/granular flows of dry materials in reduced gravity. In rapid flows, the particles interact through collisions, and the energy of the particle velocity fluctuations plays an important role in the physics. The experiment will focus on the separation of grains by properties - size, for example - that is driven by spatial gradients in the fluctuation energy of the grains. The flight experiment will consist of a shear cell that contains a mixture of two types of spherical grains. The grains will be driven to interact with two different types of boundaries on either side of the cell. The resulting separation will be observed visually.

#### **Microgravity Shear Cell Concept**

The microgravity shear cell [ $\sim 55 \text{ cm} \times 25 \text{ cm} \times 15 \text{ cm}$  ( $21.7 \text{ in.} \times 9.8 \text{ in.} \times 5.9 \text{ in.}$ )] will have two linear test sections housing a moving chain of steel spheres ( $\sim 3 \text{ mm}$ ) inside stationary walls with a  $2.5 \text{ cm}$  ( $1 \text{ in.}$ ) gap creating a  $42 \text{ cm}$  ( $16.5 \text{ in.}$ ) long straight shear area (to avoid centrifugal forces). The cell will consist of a stationary belt and a moving belt. The upper wall is roughed to provide energy fluctuations to the flow of binary spheres in the gap and the lower wall is roughed to provide dissipation of granular temperature. The side walls are transparent windows to observe the segregation of spheres of different densities across the flow under a maximum shear rate of  $50 \text{ Hz}$ , creating a  $1 \text{ m/sec}$  impact velocity.

*A concept for the Granular Media experiments is shown in the following figure. The hardware and interfaces shown are compatible with the standard FIR interfaces as outlined earlier in this document.*

## Granular Media Experiments - FIR Implementation Concept



### **B.3.1.4 Shear Rheology of Complex Fluids**

#### **Behavior of Rapidly Sheared Bubbly Suspensions**

*Dr. A. Sangani, Dr. D. Koch  
Syracuse and Cornell Universities*

This experiment explores the understanding of the physical mechanisms by which the bubbly suspensions are stabilized or destabilized. Experimental observations of bubbly flow in Earth's gravity are usually dominated by effects of the rise of the bubbles due to buoyancy in the sense that the relative motion of the bubbles, their deformation, and coalescence is dominated by gravity driven motions. Bubbly flows in microgravity are dominated by shearing motion and centrifugal forces. The aim of the research is to determine the Rheology and the equation of state for bubbly suspensions subject to both shear and gravity.

#### **Microgravity Test Section Concept**

A Couette cell with a rotating outer cylinder [30 cm in diameter  $\times$  30 cm in height, and a 3 cm gap (11.8 in. in diameter  $\times$  1.2 in. in height, and a 1.2 in. gap)] will contain a suspension of bubbles (1 mm to 3 mm diameter) with a volume fraction of 0.2 air in a salt-water solution to avoid coalescence. In microgravity, the centrifugal force and the bubble pressure act on the bubbles in a potential flow setting.

One feature of bubbly flows that is quite important in this experiment is the interaction of the bubble with the wall of the inner cylinder. If the bubbles were to slip along the wall, then they might experience relative little shear.

The velocity and volume fraction profiles are measured across the gap (every 2 mm) under multiple shear rates and for the different diameters. The inner wall shear stress and effective viscosity of the bubbly suspension are also measured.

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### **B.3.1.4 Shear Rheology of Complex Fluids (concluded)**

#### **Foam Optics and Mechanics**

*Dr. Douglas Durian  
University of California, Los Angeles*

The purpose of this experiment is to exploit the rheological and multiple light scattering technologies under microgravity conditions in order to understand how elastic characteristics vanish as the foam melts into a simple liquid as a function of varying liquid content and shear strain rates. A fluid cell will be constructed to provide a uniform shear deformation throughout the cell. The experimental apparatus will be able to generate and load the foam into the cell and be able to manage the surface of the foam adequately.

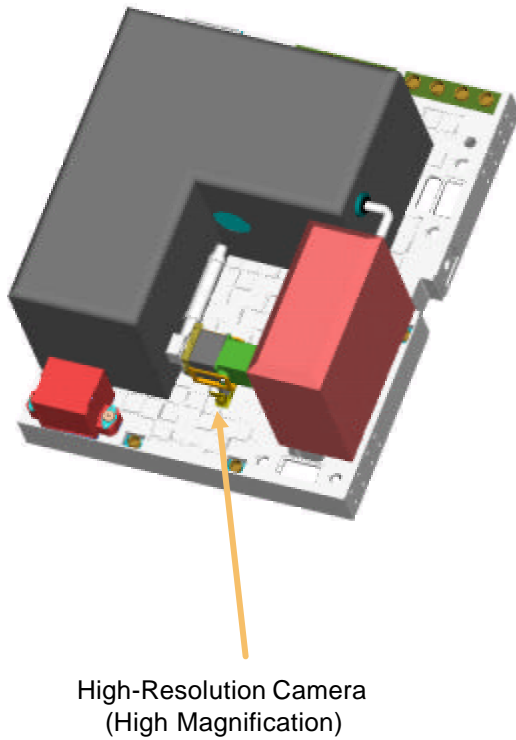
#### **Microgravity Test Section Concept**

A possible geometry would be a plate-cone device. A potential cone-plate geometry would have a flat fixed bottom, fixed cylindrical walls, with a rotating conical top surface. The radius requirement of the device could be between 5-10 cm with a potential cone angle of 0.15 radians. The top and bottom inner surfaces should be non-wetting and slightly rough to provide non-slip surfaces. The inner walls, also non-wetting, should be smooth to provide for bubble slip. The cell, whatever its ultimate design, will be constructed to provide for simultaneous microscopy, diffusive transmitted spectroscopy (DTS), diffusive wave spectroscopy (DWS), rheological measurements. Provisions will be made for foam formation and loading into the cell.

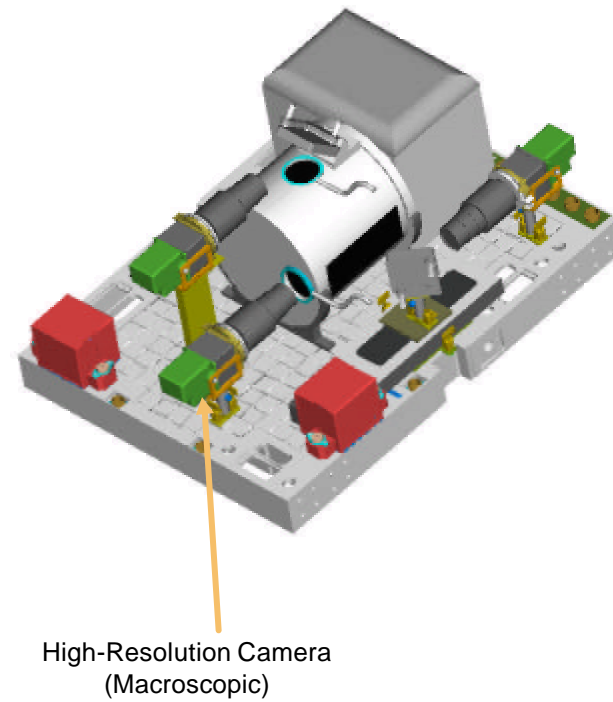
*Conceptual layouts of the shear rheology experiments integrated within the FIR is shown in the following figure. The hardware and interfaces shown are compatible with the standard FIR interfaces as outlined earlier in this document.*

## Behavior of Rapidly Sheared Bubbly Suspensions - FIR Implementation Concept

Bubbly Suspensions-Sangani



Foam Optics and Mechanics- Durian



### **B.3.1.5 Multiphase Flow Boiling-Pool Boiling**

#### **A Mechanistic Study of Nucleate Boiling Heat Transfer Under Microgravity Conditions**

*Dr. Vijay Dhir*

*University of California, Los Angeles*

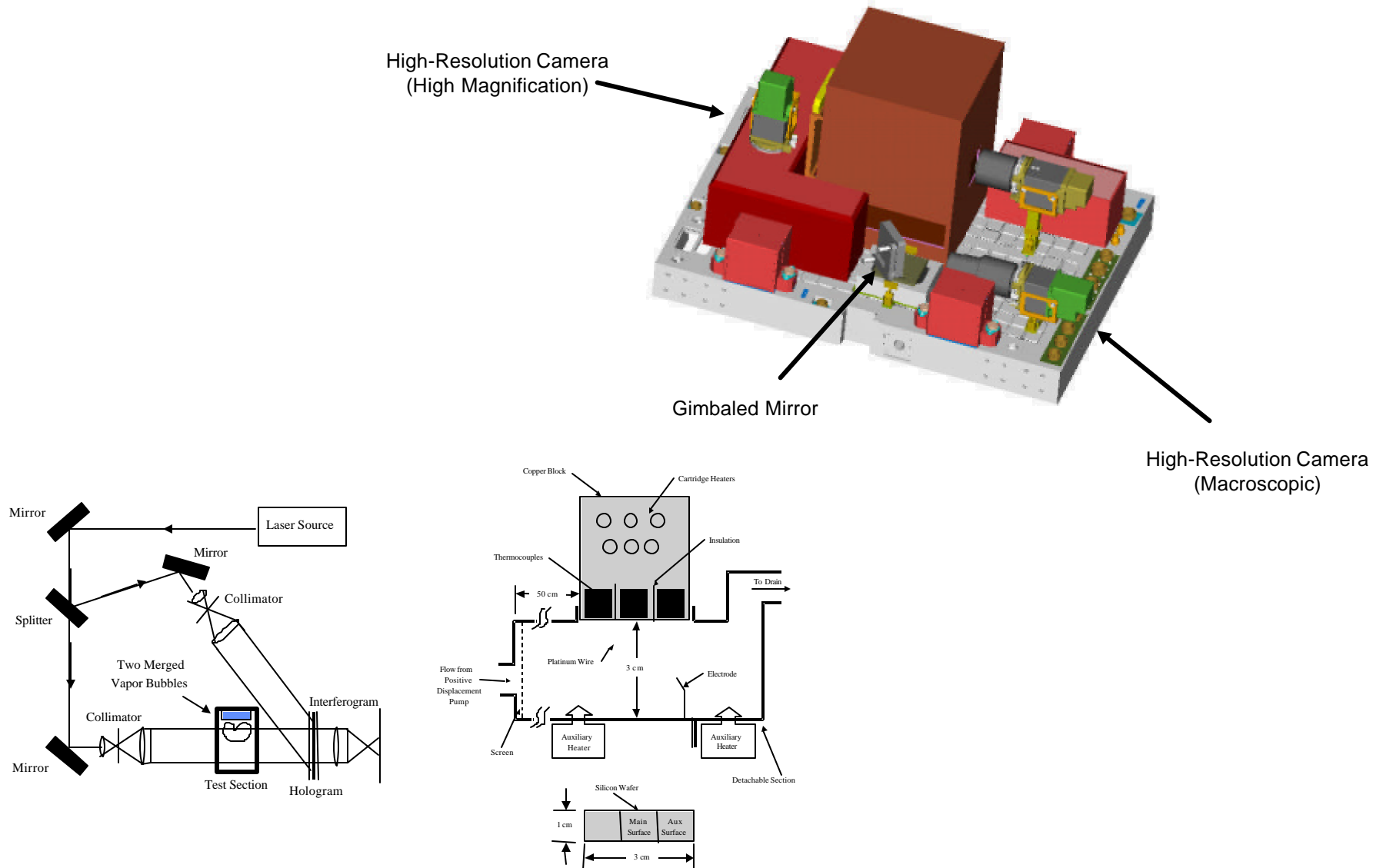
There are basically two types of experiments here, pool boiling and flow boiling. One is the study of nucleate boiling in microgravity and the other is the study of boiling mechanisms under low flow conditions. Specific interests are bubble nucleation, growth and departure, bubble merger and interactions, microlayer evaporation and condensation and the effects of recoil pressure due to phase change and liquid inertia. There will be two types of heating surfaces, commercial and ones with prescribed cavity patterns. The experiment will test for various subcooling levels, various wall super heats, two kinds of liquids, and two kinds of heater surfaces as mentioned above. It will have tests conducted for various controlled systems pressures, liquid temperatures, heat surface temperatures, flow velocities, and dissolved gas content. There are two sample fluids, PF5060 and water.

#### **Microgravity Test Section Concept**

For the pool boiling case, the chamber is one with a bellows that provides pressure control. The chamber has two wafer/heaters mounted inside it for bubble nucleation and growth studies. The PF5060 chamber is 20 x 20 x 30 cm with 15 cm dia. wafers; and the water chamber is 35 x 35 x 75 cm with 30 cm wafer diameters. For flow boiling, the test cells are 2 x 2 x 35 cm for both PF5060 and water. The wafers in this case are 1 x 15 cm in dimension. Expected flow velocities are up to 20 cm/sec.

*A conceptual layout of the pool boiling experiment is shown in the following figure. The hardware and interfaces shown are compatible with the standard FIR interfaces as outlined earlier in this document.*

## Multiphase Flow Boiling/Pool Boiling - FIR Implementation Concept



### **B.3.1.6 Contact Line Hydrodynamics**

#### **Microscale Hydrodynamics Near Moving Contact Lines**

*Dr. Stephen Garoff  
University of California, Los Angeles*

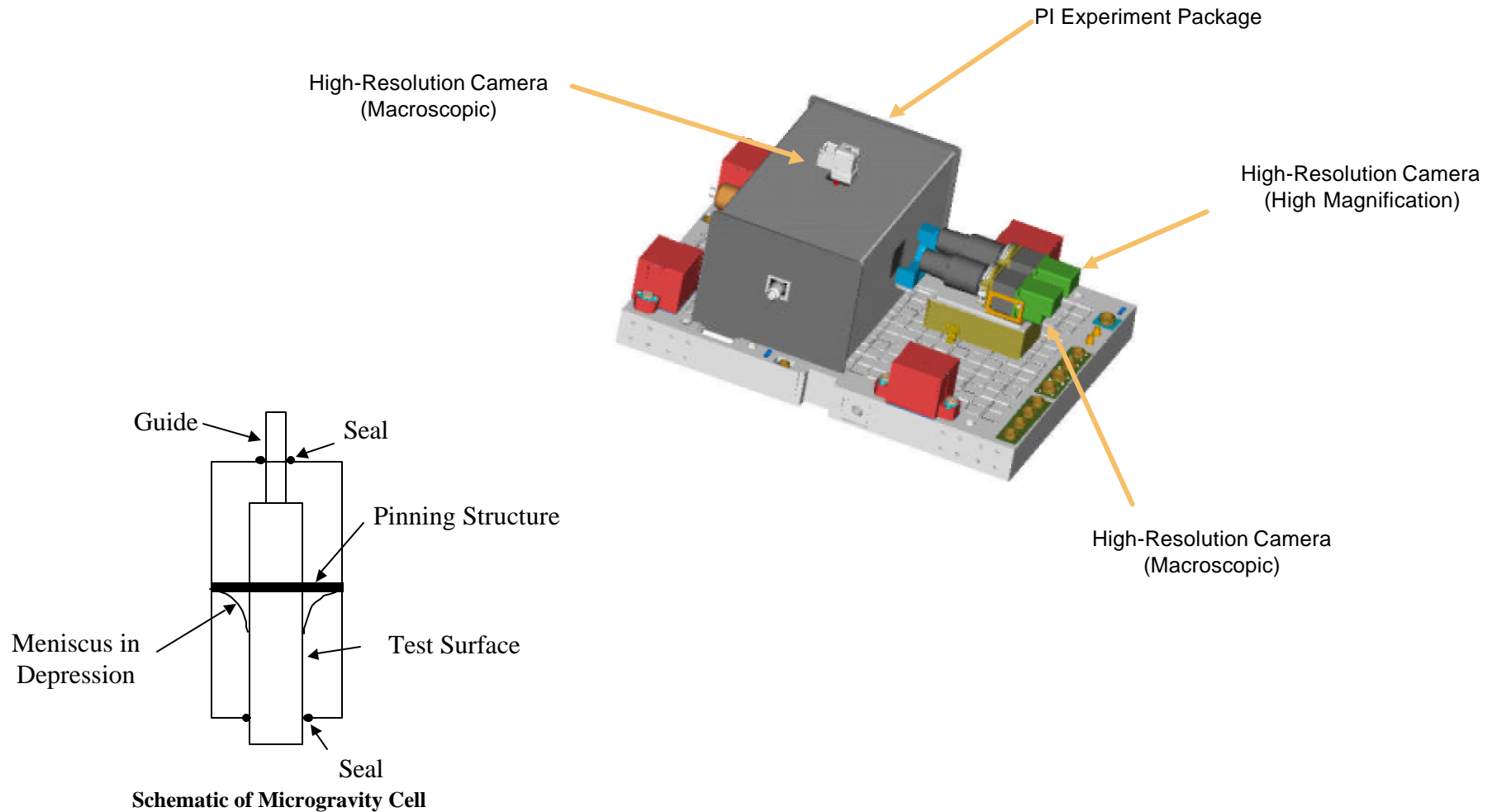
The purpose of the experiment is to obtain the measurement of the flow fields and the interface shapes very close to a dynamic contact line moving at constant velocity. The test cell will be an open container of liquid with a flat free surface, enforced in microgravity by a pinning surface. There will be a hole in the pinning surface for a rod to be inserted. The free surface can either take on a depressed shape for those cases in which the rod is inserted into the liquid or can come out above the nominal free surface position for those cases in which the rod is pulled out of the container. There will be two samples of varying viscosity; 60000 cSt and a 200 cSt methyl-terminated PDMS.

#### **Microgravity Test Section Concept**

A cylindrical annular geometry is envisioned for this experiment. It will be transparent for optical viewing purposes. A cylindrical tube will either be inserted or retracted at a constant velocity to engender the dynamic contact line behavior. The free surface of the liquid must be pinned to the outer surface so that the interface to achieve stability. It is also anticipated that a rectangular outer vessel will be necessary (housing an optical index-matching fluid) to correct any refractive problems obscuring imaging inside the cylinder. It is anticipated that the inner rod must be at least 2 cm in radius, and that the gap dimensions (defined as the difference between the outer and inner radii) will be variable between 1, 2.5, and 5 cm. The cell depth will be at least 2.5 times the gap dimension.

*A conceptual layout of the experiment is shown in the following figure. The hardware and interfaces shown are compatible with the standard FIR interfaces as outlined earlier in this document.*

## Contact Line Hydrodynamics- FIR Implementation Concept



## B.3.2 FCF FIR On-orbit operations

The FIR must accommodate a wide range of experiments having a broad variety in types of samples, types of measurements, and other experiment unique factors. In order to accommodate this wide variety of experiments, the FIR is modular; with its capabilities easily configured to the requirements of a particular experiment or series of tasks. Many off-the-shelf hardware components are integrated within the FIR including plug-in computer boards to maximize versatility and replicability of provided hardware for the interfacing scientist. The FIR allows the ability to raise scientific data quality and quantity while lowering per-experiment costs relative to other ways of performing such experiments.

Crew members are nominally required to execute experiments on the FIR. However, crew time available for on-ground training and direct experiment interaction aboard the ISS will be typically limited requiring simple procedures for crew intervention, minimizing crew observation of experiments and limiting the crews ability to make on-orbit decisions. What the FIR offers to the Principal Investigator (PI) is the ability for the “expert” to participate directly with their experiment as in their own laboratory through remote operation and direct observation. Observation provides the PI the majority of required experiment information, allowing self-assessment of performance and providing cues for automated and required non-automated intervention/change for best results. The FIR interacts and controls an experiment through a partnership with the scientist on the ground. Ground based systems will further enable scientist interaction with other researchers at other remote locations.

Operations will be primarily conducted from the GRC Telescience Support Center (TSC). Remote PI sites will be provided with the necessary equipment to conduct operations.

The Ground team at the TSC will monitor the facility health and status and control Facility functions. The PIs will control their experiments from the TSC or their remote sites by uplinking new test parameters through the TSC. The Crew is not the primary FCF operator.

Downlink Data will be stored at the TSC until it can be distributed to the PI site.

The FCF will limit its use of the Crew to experiment setup, reconfiguration, and maintenance. These activities are described as follows:

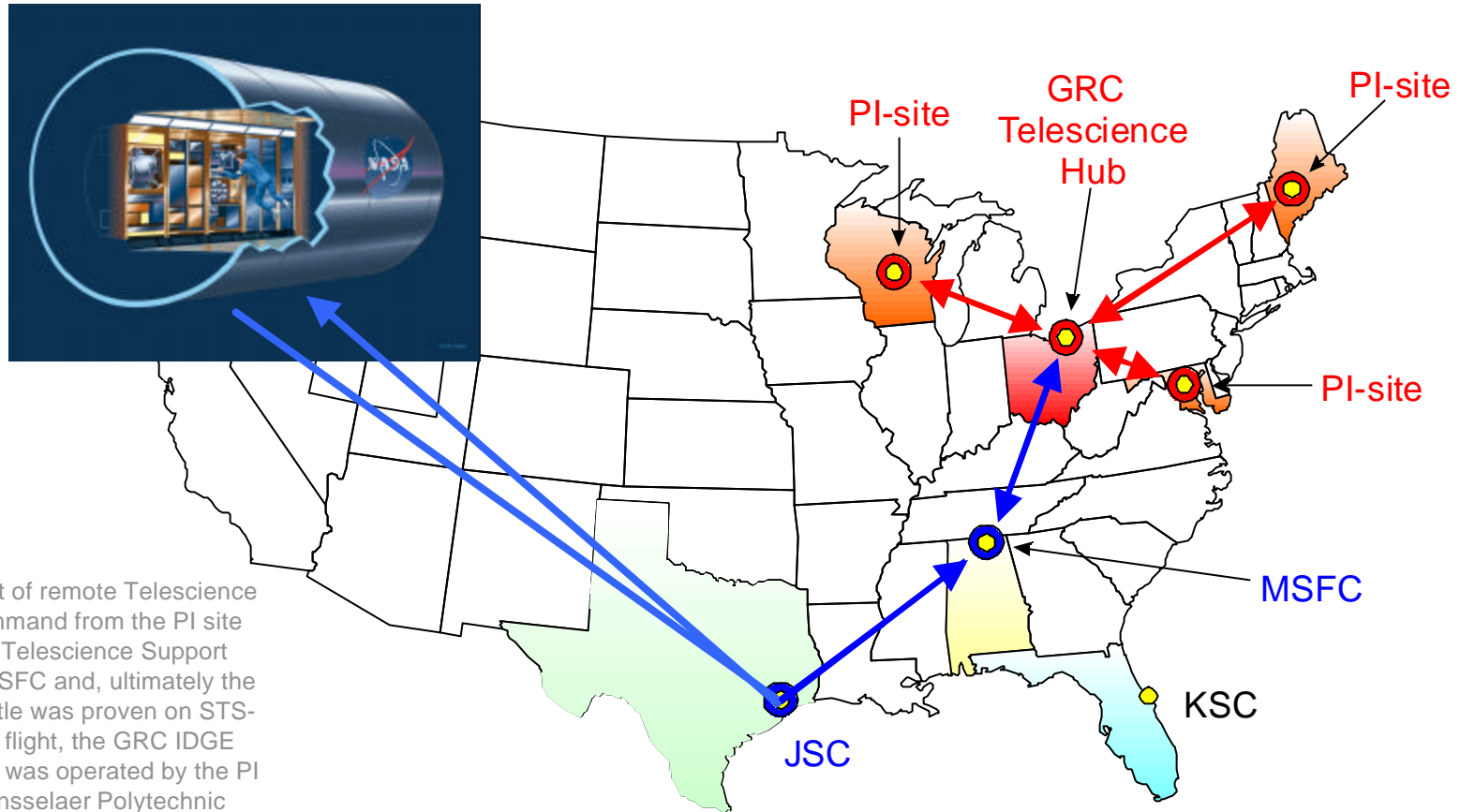
- **Setup** encompasses all activities required for initial experiment operations such as installing gas bottles and PI hardware.
- **Reconfiguration** involves moving diagnostics to new locations, refocusing, replenishing consumables, and so on.
- **Maintenance activities** consist of recalibrating or replacing sensors, replacing filters, and conducting scheduled maintenance.

The capability will exist to control the FCF FIR from a dedicated on-orbit laptop.

*The FCF FIR Telescience Hub operations concept is shown in the following figure.*

## FCF FIR Telescience Hub Operations Concept

ISS US Laboratory Module



The concept of remote Telescience with full command from the PI site through the Telescience Support Center to MSFC and, ultimately the Space Shuttle was proven on STS-75. On that flight, the GRC IDGE experiment, was operated by the PI from the Rensselaer Polytechnic Institute in Troy, N.Y.

### B.3.2.1 CDMS Operations Overview

The FCF FIR Command and Data Management System (CDMS) operates at multiple levels, with each level having its own tasks and responsibilities. Tasks for an experiment are broken down into three phases: the Pre-experiment Phase, the Experiment Run Phase, and the Post-experiment Phase.

#### **Pre-experiment Phase**

The Pre-experiment Phase is the time in which experiment hardware and software is uploaded, configured, aligned, calibrated, and so on. The Station Support Computer (SSC) and Fluids IOP can be used to ready the rack hardware and software for specific experiment runs. The SSC provides the crew an interface for control and operation of the Facility and the experiments.

#### **Experiment Run Phase**

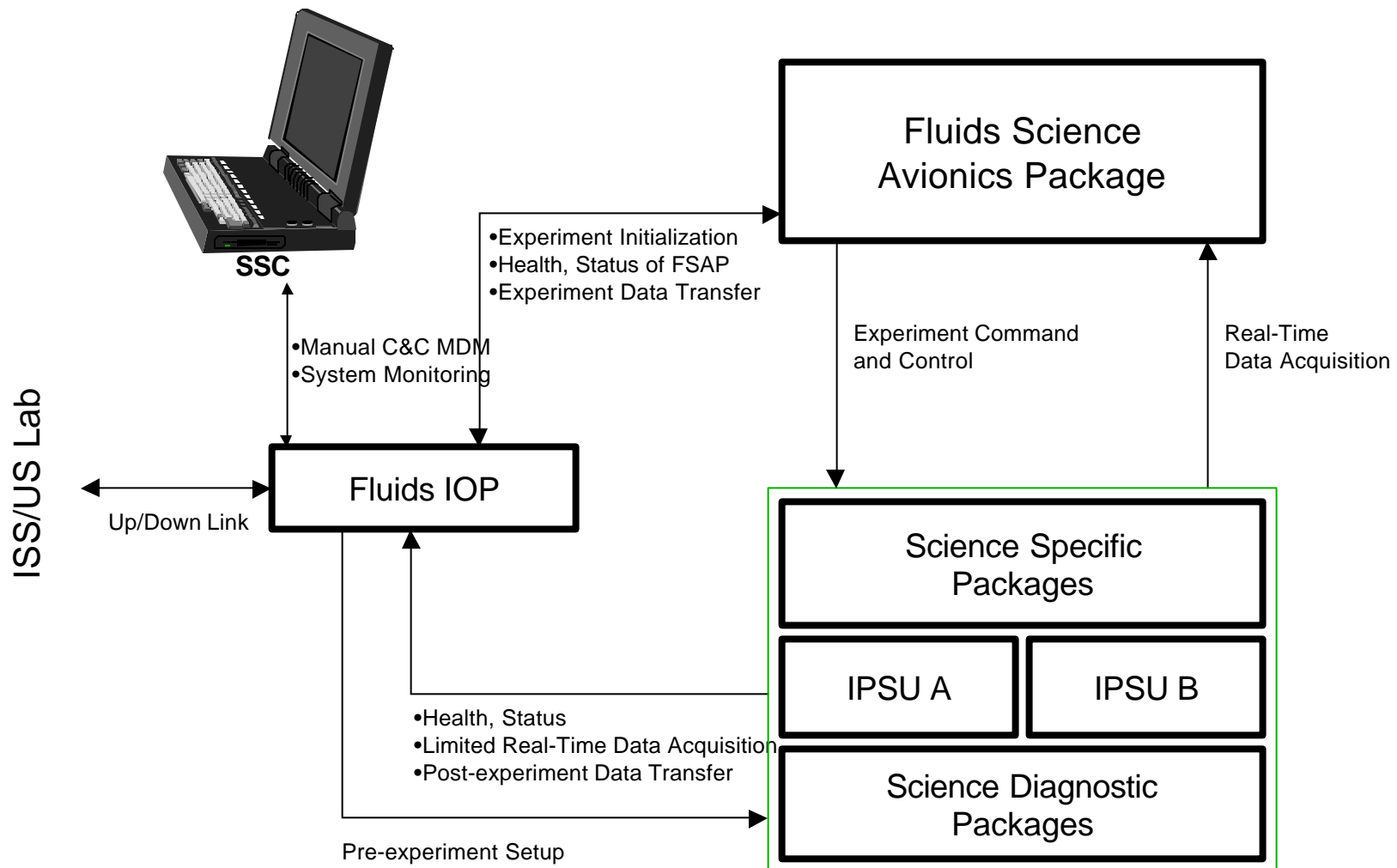
Experiment runs can be initiated from the SSC manually or remotely via the IOP. Once this phase is initiated, the FSAP performs the specific tasks required to perform the experiment. The IOP and SSC are used for health and status monitoring, as well as some limited passive data acquisition. The IOP also provides a timing signal to the FSAP for critical science data time stamping.

#### **Post-experiment Phase**

Once the experiment run(s) have been completed, science data is post-processed. This phase includes data compression, downlink, and any cleanup tasks that may be required. The Post-experiment Phase may be initiated remotely via the IOP, from the SSC, or automatically by the FSAP following the completion of the Experiment Run Phase.

*The Command and Data flow through the three phases of FIR operation is shown in the following figure.*

## FCF FIR CDMS Operation



### B.3.2.2 PI Experiment Set-up Scenario

Each new experiment will involve a crew member to install and configure the FCF FIR diagnostics per the requirements of the particular experiment. When setting up a new experiment, the crew member will first be required to fold open the FCF doors covering the un-powered FIR to gain access to the optics bench where the experiment will be configured.

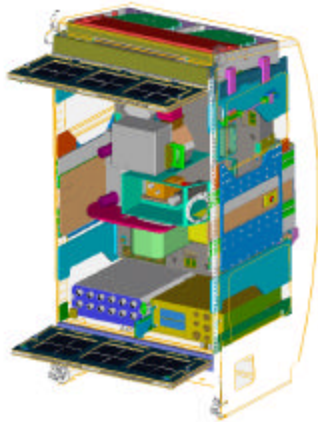
Prior to experiment installation, if FIR standard diagnostics need to be reconfigured (experiment-unique) on the back side of the optics plate, the astronaut can gain access by retracting the pins (3 total) that secure the optics plate in its operational position. The optics plate may then be slid to its forward crew access position and locked in place. The astronaut will next activate the tilt mechanism designed to control translation of the optics plate to its extended position. The astronaut will then unstow/install PI-specific diagnostics/electronics and re-configure provided facility diagnostics. The tilt mechanism is again engaged to translate/fold the optics plate back to its upright experiment crew access position.

The crew member will then unstow and install the PI-specific experiment hardware on the front of the optics plate. After installation and attachment of the major components to the optics plate, the astronaut will be required to connect the front interfaces and to provide rough alignment of diagnostics (precision alignment will be done autonomously from the ground). The optics plate is unlocked from its forward position and slid back to its operational position in the rack. The optics plate pins are engaged to lock the optics plate for operations. Lastly, the crew member closes the door. Experiment initiation can now either be initiated by the crew via a laptop or from the ground.

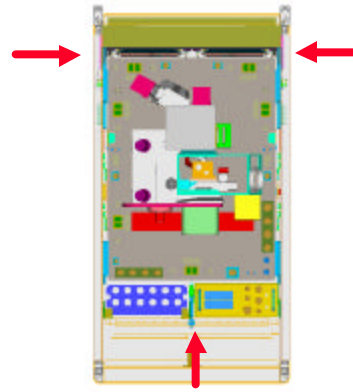
*The FCF FIR Flight Operations concept is shown in the following figures.*

## FCF FIR Nominal PI Set-up Scenario (1 of 2)

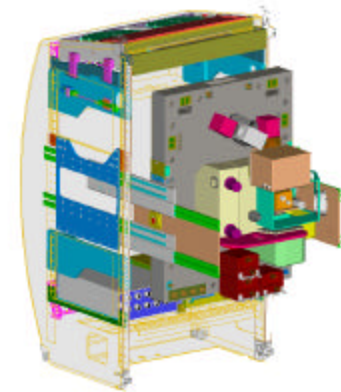
**Step 1**  
Fold Open Doors



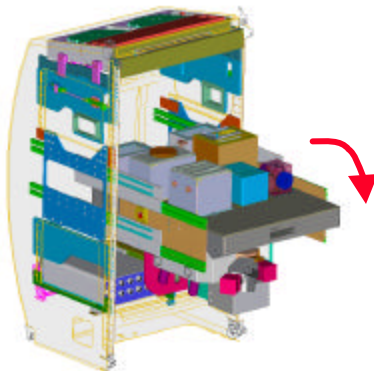
**Step 2**  
Retract Pins  
(No Tools)



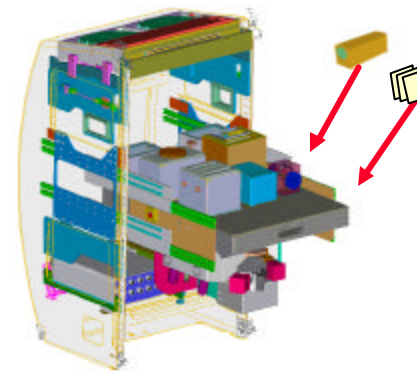
**Step 3**  
Translate Optics Bench Forward



**Step 4**  
Fold Down Optics Bench  
(No Tools)



**Step 5**  
Unstow/install PI-Specific Diagnostic/Electronics  
and Configure Facility Diagnostics

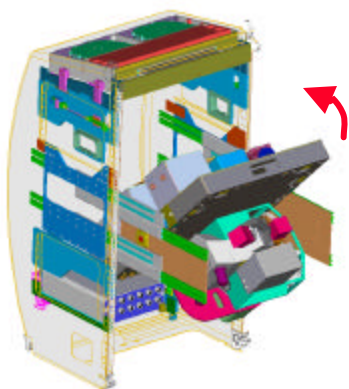


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## FCF FIR Nominal PI Set-up Scenario (2 of 2)

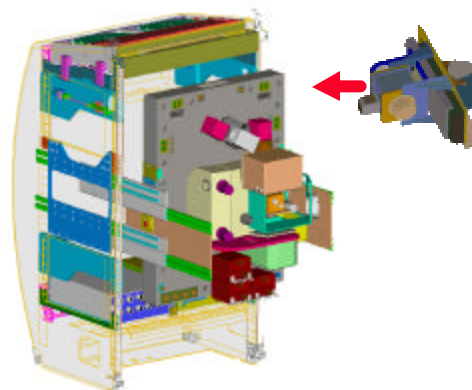
### Step 5

Fold Up Optics Bench



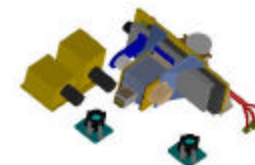
### Step 6

Unstow/Install Experiment



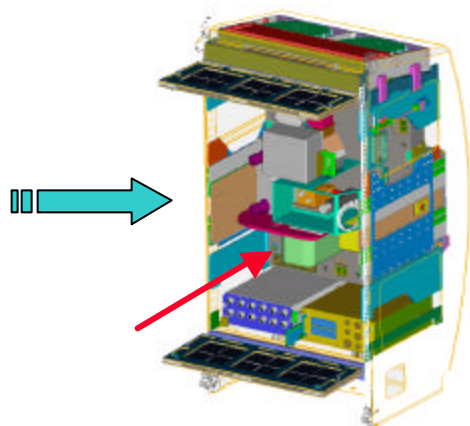
### Step 7

Connect Interfaces and  
Align Diagnostics



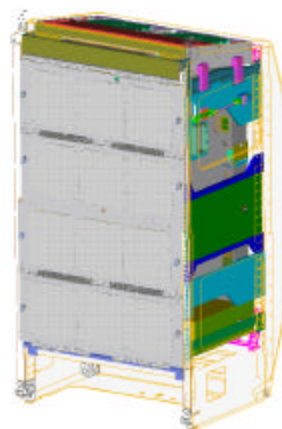
### Step 8

Push Back Optics Plate and  
Engage Optics Plate Pins



### Step 9

Close Door



### B.3.2.3 Operational Scenario

Once the FIR is powered up and operating nominally, the PI will be enabled for commanding experiment-specific equipment. The PI will then issue commands to perform an experiment run. This may be the parameters for a single test point, or a series of test points.

The PI can monitor sensor data and low resolution video to insure the experiment is operating nominally. Data for science analysis will be downlinked post-test. Based on real-time data or post-test data, the PI can adjust the test parameters for subsequent test runs. When the current operations window is over, the FCF will be shut down by the operators at the TSC.

Once experiment operations commence, the FIR will operate on a daily basis. A typical ops day will be 8 to 10 hours, and will allow up to 3 typical experiment test points to be run depending on resource availability and PI desires. Expendables will be replenished as needed.

A typical flight day would begin with the ground operators reporting to station prior to the scheduled start of the experiment. The current on-board schedule will be reviewed and any modifications to the experiment timeline will be evaluated. All communications between the operations sites will be verified at this time. Once the PI and FCF operations team are prepared the POIC will be informed that the FCF is ready for power up.

Once power is enabled at the FCF interface the Input/Output Processor (IOP) begins its startup routine. A series of self-tests will be executed and the results will be made available to the operators. Status of the Electrical Power Conversion Unit (EPCU) will also be determined. When the startup is completed the FCF will be waiting for commands to begin experiment configuration. Health and status information will be available during the period where the FCF has power.

### B.3.2.4 Crew Interaction

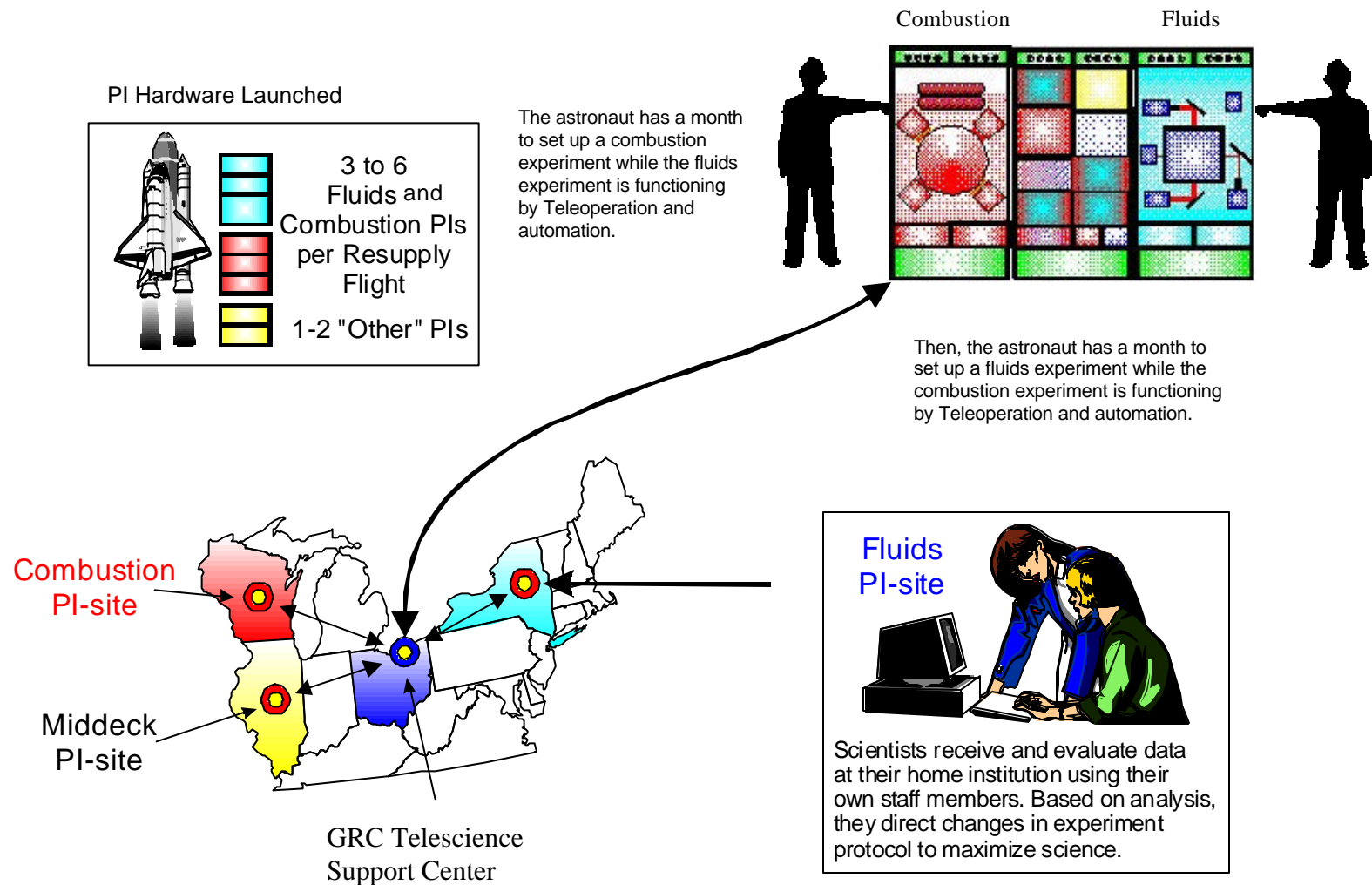
Expected interaction of the crew with the flight hardware require that the appropriate design and procedural controls are in place to prevent a hazard. Routine operations accomplished on the ground must be rigorously controlled on-orbit due to the potential effect that could result if a hazard occurs. Any color-coded markings must be accompanied by alpha-numeric notation. The FIR will be designed such that any required access to hardware during flight or ground operations can be accomplished with minimum risk to personnel.

The FIR design shall not impede emergency IVA egress to the remaining contiguous pressurized volumes. Crew egress time from experiment apparatus shall be less than 30 seconds. Local visual indicators shall not be used as the only source of safety monitoring unless the crew is actively engaged in payload operations at the visual indicator location. Payload equipment shall not be reconfigured, erected, or operated upon in a manner which could present a hazard to the crew, ISS/Orbiter, or which would make it unsuitable for safe return if the item is planned for return.

The need for hazard detection and safing by the flight crew to control time-critical hazards will be minimized and implemented only when an alternate means of reduction or control of hazardous conditions is not available. When implemented, these functions will be capable of being tested for proper operations during both ground and flight phases and shall use existing ISS systems for fault detection and annunciation. Likewise, payload designs should be such that real-time monitoring is not required to maintain control of hazardous functions. With PSRP approval, real-time monitoring and hazard detection and safing may be utilized to support control of hazardous functions provided that adequate crew response time is available and acceptable safing procedures are developed. Flight or ground crew hazard detection and safing actions are not available for ascent and descent flight phases.

*The FIR on-orbit flight operations concept is shown in the following figure.*

## FCF FIR Flight Operations Concept



## **Appendix C – Shared Accommodations Rack (SAR)**

## Table of Contents

<b>C.1 Shared Accommodations Rack Overview</b>	<b>C-4</b>	<b>C.3 Utilization &amp; Operations</b>	<b>C-44</b>
C.1.1 Purpose of the SAR	C-4	C.3.1 SAR/PI Hardware Integration	C-44
C.1.2 Concept of the SAR	C-6	C.3.2 FCF SAR On-orbit Operations	C-46
C.1.3 Operational Concept for SAR	C-6	C.3.2.1 SAR CDMS Operations Overview	C-48
		C.3.2.2 SAR Set-up Scenarios	C-50
		C.3.2.3 Operational Scenario for SAR Experiments	C-56
		C.3.2.4 Crew Interaction	C-56
<b>C.2 Shared Accommodations Rack System Design</b>	<b>C-10</b>		
C.2.1 SAR Completes the FCF System	C-10		
C.2.2 SAR System Overview	C-12		
C.2.3 Major Components	C-12		
C.2.3.1 Science Support Element	C-12		
C.2.3.2 Optics Bench Assembly	C-14		
C.2.3.3 Science Avionics	C-20		
C.2.3.4 SAR Middeck Locker Accommodations	C-22		
C.2.3.5 SAR Shared Resources Concept	C-24		
C.2.3.6 Core Element	C-26		
C.2.4 SAR Metrics	C-38		

## **Appendix C.1 Shared Accommodations Rack Overview**

## C.1 Shared Accommodations Rack Overview

This document represents the current concept for the SAR and will be updated as necessary to reflect changes to the baseline concept. The SAR will support the NASA Microgravity Science and Applications Division (MSAD) and the NASA Human Exploration and Development of Space (HEDS) program objectives requiring sustained systematic research in fluid physics and combustion. This document is intended to facilitate communication between the various project groups and contains the necessary design data for team members to make technical recommendations and decisions during the early stages of the development process including:

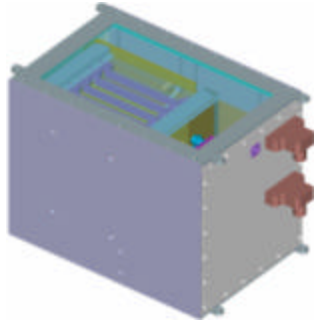
- **Technology, working principle(s), and physical form** of the SAR and its subsystems
- SAR and subsystem physical and performance **metrics**
- High-level functional **capabilities**
- **Constraints** that limit the subsystem design solution

### C.1.1 Purpose of the SAR

The FCF SAR is a modular, multi-user facility in the US Laboratory Module of the ISS. It has two primary functions: provide additional resources to the FIR and CIR; provide accommodations for SAR science experiments. The SAR, which is similar to the FIR, consists of two elements: **1)** an Experiment Assembly Element that accommodates the SAR experiment packages and the science support packages for experiments conducted in FIR and CIR; and **2)** a Core Element that provides the overall infrastructure necessary to support experimentation. The Core Element is comprised of subsystems that enhance, interface, and distribute ISS services. The Experiment Assembly Element is comprised of an optics bench with interfaces to the core element subsystems, the ISS services and the FIR and CIR. It will provide the SAR experiments with the best resource allocations allowable by the ISS and will provide the fluids and combustion experiments in the FIR and CIR with shared resources.

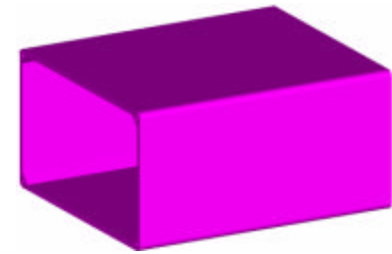
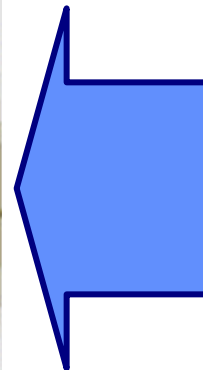
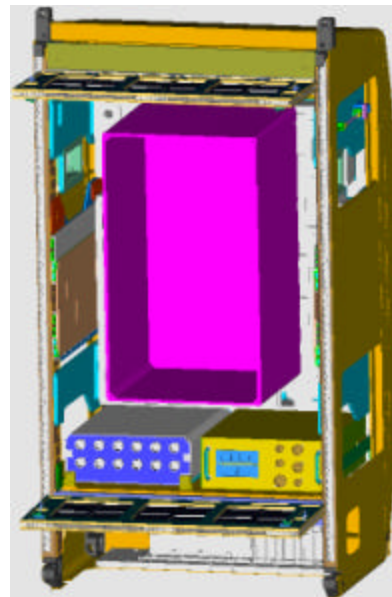
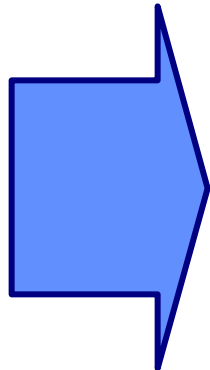
*The elements of the FCF SAR hardware concept are shown on the following page.*

## FCF Shared Accommodations Science Support



### Avionics Packages

- **Electrical Power Control Unit** for electrical power distribution, conversion, and control of SAR equipment
- **Input/Output Processor** for facility command, control, and health and status monitoring
- **Image Processing Storage Units (2)** for combustion and fluids image acquisition, processing, and storage
- **Video Monitor** for status monitoring of facility operation by astronauts
- **Laptop Computer** for crew interface command, data viewing and software and table up-load functions



### Multipurpose Science Volume

- **General Purpose Optics Plate** for PI Hardware, Middeck Lockers (Small science payloads may be run in the SAR, if desired)
- **Large Contiguous Volume for Bulky Hardware** (i.e., up to 28 PU for large PI apparatus, high speed imaging equipment, etc.)
- **On-Orbit Spares Stowage** to maximize system readiness & thru-put
- **Multiple PI-Specific Hardware** available on-orbit at all times to maximize flexibility and thru-put
- **Powered PI Stowage Volume** (e.g., fluid sample preparation and storage)
- **Off-Line Combustion Waste Gas Storage and Cleaning** (i.e., Combustion Gas Accumulator and Exhaust Vent)
- **Chemical/Physical Analysis Capability** for on-orbit fluid sampling and analysis (i.e., Mass Spectrometer)
- **Calibration Apparatus** for FCF equipment requiring regular on-orbit calibration

### C.1.2 Concept of the SAR

The goal of the SAR concept is to increase the cost-effectiveness and the science effectiveness of the FCF by (1) providing additional and shared resources to experiments in the FIR and CIR and (2) providing accommodations for experiments not readily performed in the FIR and CIR, for example, mid deck locker type experiments. The concept of the SAR is based on the following guidelines:

- Utilize **ISS-provided common hardware**
- Utilize **FCF common hardware architecture** and subsystems.
- Utilize **modular assembly** to optimize access for flexible reconfiguration and maintenance while minimizing impact on crew time.
- Utilize **modular up-gradable hardware and software concepts** to permit evolutionary implementation of capabilities to meet selected requirements or improvements
- Utilize **FCF diagnostic and measurement subsystems** that are chosen to optimize the long-term benefits to the science program.
- Make maximum use of the **FIR and CIR design concepts** already developed.
- Develop **designs and operational concepts** to perform the following functions:
  - **Maximize** accessibility and flexibility for SAR experimenters to use SAR capabilities while minimizing requirements for up- and down-mass.
  - **Maximize** accessibility and flexibility for FIR and CIR experimenters to use SAR resources.
  - **Optimize** the implementation and the operation of safety-related systems and documentation

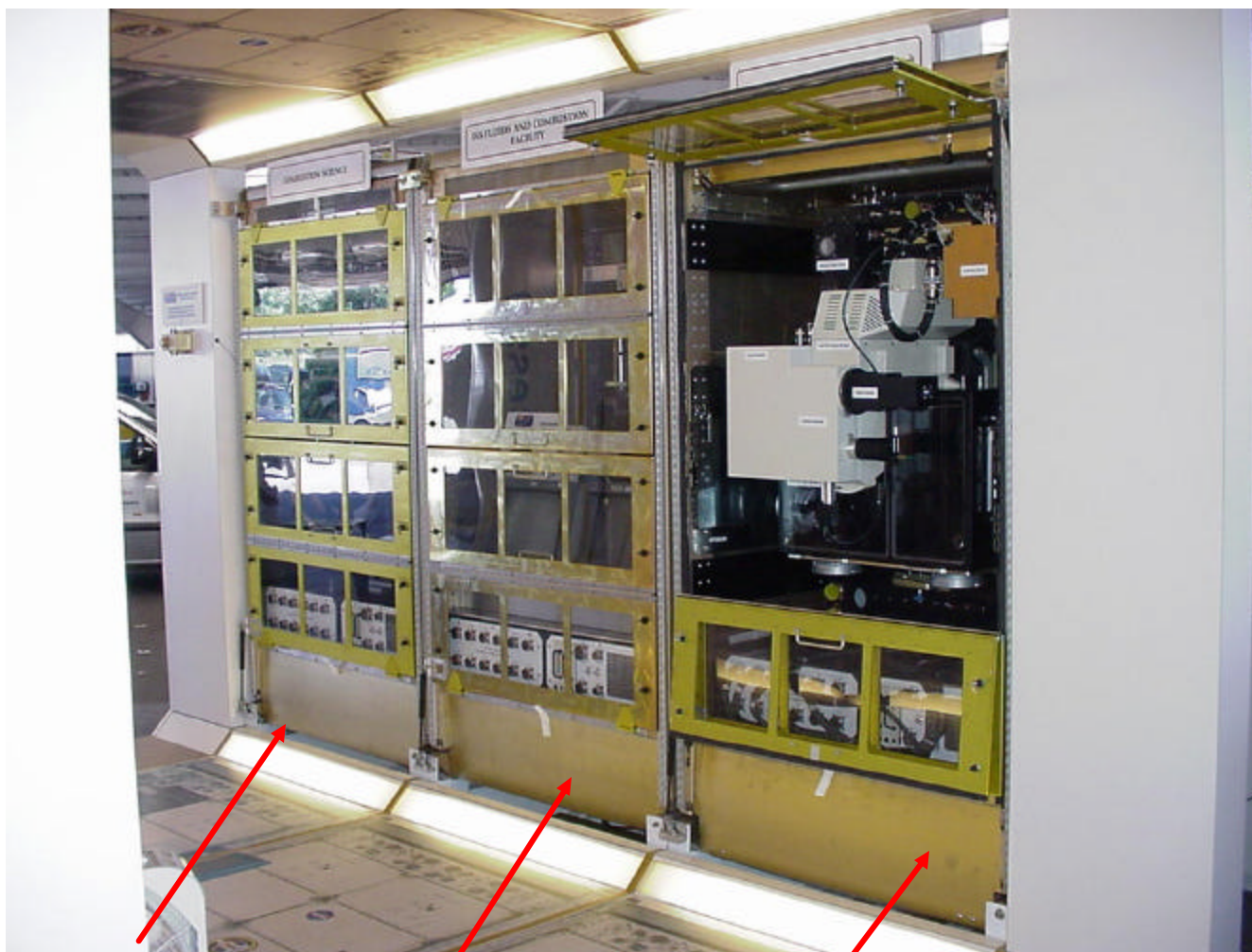
### C.1.3 Operational Concept for the SAR

As with FIR and CIR, SAR is to be a modular multi-user facility. It is designed to take advantage of the International Space Station (ISS) research environment, specifically, long term micro-gravity, multiple user access, and some ability for on-orbit re-configurability of experiments. The SAR concept is designed to support FIR and CIR experiments by providing additional or shared resources.

The SAR involves the development and deployment of all on-orbit and ground equipment that is (1) common to, or needed by, most proposed SAR experiments and (2) that is to be a shared resource with FIR and/or CIR. Hardware that is unique to a SAR experiment will be provided by the Principle Investigator. As with FIR and CIR the SAR science measurement capability must be verifiable and representative of “state of the art”. The intent is to provide the science community, including FIR and CIR experimenters, with the most accurate instrumentation and diagnostic capabilities. This should reduce experiment development time and cost by eliminating the need to develop unique instrumentation. Reduced development time and cost should encourage experimenters to design experiments for the facility.

*The Shared Accommodations Rack (SAR) is shown in the figure on the following page.*

## ISS FCF in U.S. Lab Module Mockup



Combustion  
Integrated Rack  
(CIR)

Shared  
Accommodations  
Rack (SAR)

Fluids  
Integrated Rack  
(FIR)

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## **Appendix C.2 Shared Accommodations Rack System Design**

## C.2 Shared Accommodations Rack System Design

### C.2.1 SAR Completes the FCF System

This SAR rack will enable the FIR and the CIR to offload/enhance their diagnostic capabilities. This, in turn, will increase resource allocation/capability to science payloads. Due to the pace of technological advancement, the delayed deployment of SAR can facilitate adding hardware with significantly greater capabilities. Design considerations can be made for the types of capabilities that are expected.

In the initial on-orbit configuration, the FIR and CIR operate autonomously. Each FIR and CIR IPSU supports one High Resolution monochrome digital camera. Each camera may have multiple axes of motion control support. All station command and data interfaces are initially provided through the individual science rack IOP, including a crew laptop interface. Station interfaces include a HRDL, MRDL, and 1533B C&C interfaces. When the SAR is available, communications links are installed for data collection and command and control between the FIR, CIR and SAR with the SAR now the primary interface with ISS.

Installation of the SAR facilitates:

- Add Fiber Optic Transmitters/Receivers to CDMS packages that require multiple channels of TTL communications.
- Install fiber optic and/or Firewire cables between the FIR and SAR.
- Having Fiber Optic connections available for data transmission increases the potential to locate diagnostic and computer support hardware in the SAR.
- Additional volume in the SAR could facilitate additional storage media, post processing hardware, video switching equipment, etc. Fiber optic connections would link the resources in all three racks.

*The hardware overview of the Fluids Integrated Rack (FIR) is shown in the figure on the following page.*

## Shared Accommodations Rack is a Versatile Part of the FCF Architecture



## C.2.2 SAR System Overview

The FCF SAR is a modular, multi-user facility that accommodates science experiments on board the US Laboratory Module of the ISS where SAR is exposed to the microgravity environment. The SAR consists of two elements: 1) a Science Support Element consisting of an Optics Bench Assembly with science diagnostic and science specific packages for experiments; and 2) a Core Element that provides the overall infrastructure necessary to support experimentation. The Core Element is comprised of subsystems that interface, enhance, and distribute ISS services.

## C.2.3 Major Components

### C.2.3.1 Science Support Element

The primary structure of the Science Support Element within the SAR is the Optics Bench Assembly. Mounted to the Optics Bench Assembly will be various Science Diagnostic Packages and PI Science Specific Packages to accomplish the facilities FCF mission.

The following packages , which are identical to those in the FIR, comprise the Science Support Subsystem:

- **Optics Bench Assembly**
- **Imaging Processing Storage Unit (IPSU)**
- **Fluids Science Avionics Package (FSAP)**

*The SAR science support capabilities are shown in the figure on the following page.*

## Science Support Capabilities Overview

### **SAR Features:**

- Easy access via fold down bench
- Diagnostics easily reconfigured, replaced/interchanged on optics plate
- Accommodates many experiment configurations and disciplines

### **Image Processing Packages:**

- Supports high-speed digital cameras
- Data collection at 100 MB/sec

### **Environmental Control:**

#### Air and Water

- 500 W of cooling (air/water) available to PI Unique H/W
- Rack Structural Augmentation

### **Rack Structure:**

- ISPR - 4
- Standard ARIS
- FCF Slide Package
- Pin Assembly

### **Door:**

- Structural augmentation
- 20 inches from front of optics plate to rack door

### **Electrical Power:**

#### Electrical Power and Control Unit (EPCU)

- 48 Switched, 28 Vdc Channels
- Each Channel limited to 4 A
- Power Regulated to 28 Vdc

### **Software:**

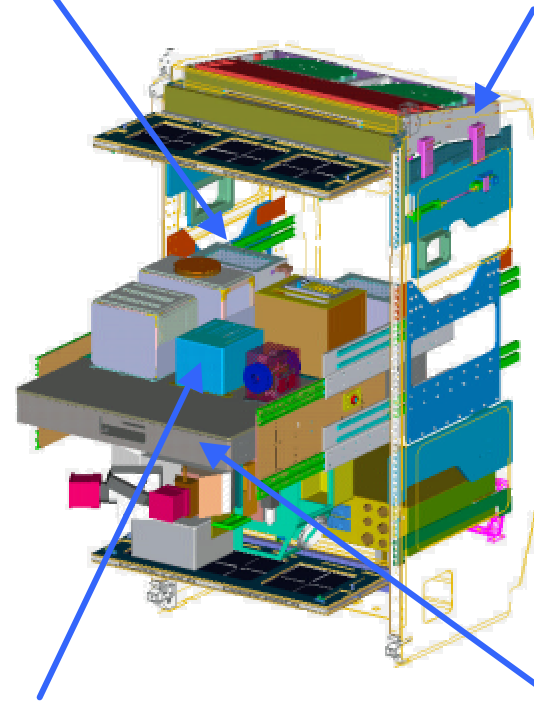
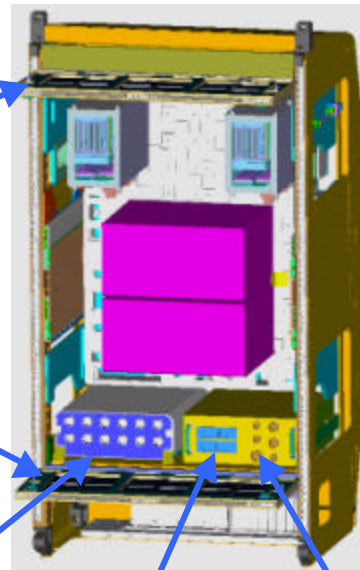
- Embedded Internet Technology
- Allows for PI interaction at home site

### **Avionics:**

- ISS Command and Data Interface
- Supervisory Control and Data Acquisition for Experiments
- 48 Digital I/O, optically isolated
- CAN Interfaces to Test Section and IOP

### **Optics Plate:**

- Width: 89.5 cm (35.25 in.)
- Length: 119.4 cm (47 in.)
- Depth: 12.1 cm (4.75 in.)
- Wiring internal and external to plate



### C.2.3.2 Optics Bench Assembly

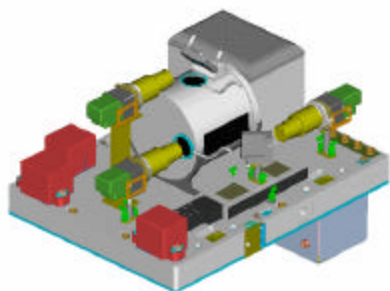
The Optics Bench Assembly, which is identical to that in FIR, provides the structural support, mounting and resource interface locations for all FEA hardware. The front side of the plate is an optical bench providing standard hole spacing of 25 mm and a stable thermal environment for experiment specific hardware and applicable diagnostics packages. The back is a mounting plate that is dedicated to the following multi-function, non-intrusive optical diagnostics packages, and to the science avionics support package:

- **Volume** - The optics bench assembly provides nearly 1 square meter of surface area on which experiment hardware may be configured. A maximum of approximately 492 liters of science specific volume can be accommodated with the front of the optics plate bare ( i.e. no FIR provided diagnostics).
- **Standardized Interfaces** - Standardized interfaces will be provided for electrical power, video and digital data acquisition, motor control, vacuum ventline, GN<sub>2</sub>, thermal control, and light detection circuitry interfaces.
- **Mounting** - Precision mounting/locking of PI-specific hardware/test cells and components will allow critical imaging applications such as interferometry and micro-imaging to be performed. Alignment of components will be performed via on-board processor or teleoperative control of component translation stages.
- **Containment** - During experiment operations, the FEA will provide the Optics Bench Assembly protection against the contamination of sensitive optics by U.S. Lab Module air and light, as well as serve as a barrier against escape of internal laser radiation and frangibles.

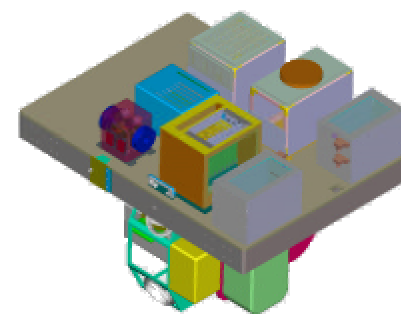
- **Thermal Control** - The optical-bench and mounting surfaces of the Optics Bench Assembly will be cooled via forced air circulation to the ISS moderate temperature water loop. Water loop access will additionally be available for the PI-specific equipment. The use of materials with near-zero coefficients of thermal expansion and heat-source isolation will allow maintenance of precision alignment for optical components. science diagnostic packages are nominally configured on the back side of the Optics Bench Assembly to allow thermal isolation to critical science specific hardware. Air flow on the front side of the plate will nominally be allowed for thermal control and smoke detection. Provisions will also be made for power and control of PI-provided thermoelectric coolers where necessary to meet stringent thermal control requirements.

*An overview of the SAR/FIR Optics Bench Assembly concept showing both the science-specific and science-support sides of the Optics Bench Assembly is shown in the figure on the following page.*

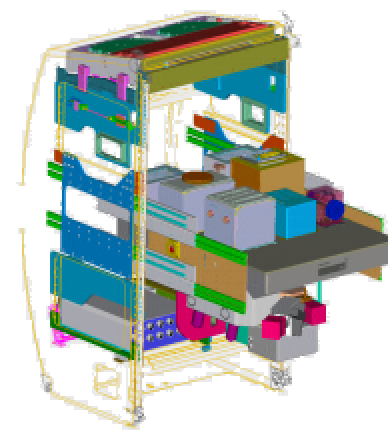
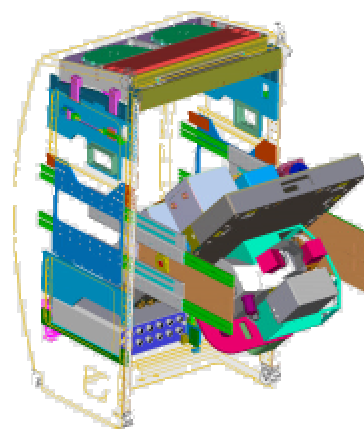
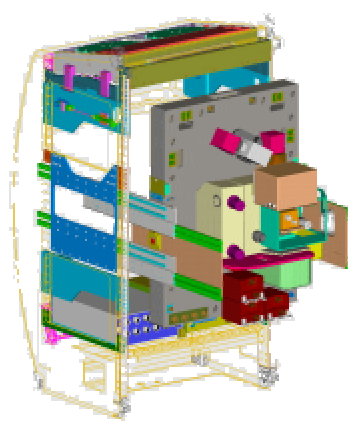
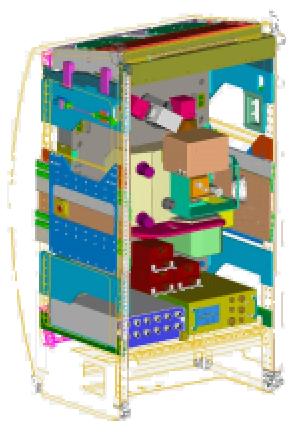
## SAR/FIR Optics Bench Assembly Overview



**Optics Bench Front**  
*Science*



**Optics Bench Rear**  
*Science Support*



*FIR/SAR Optics Bench: Operational to Diagnostic Reconfiguration Orientations*

### C.2.3.2.1 Optics Plate Description

The SAR optics plate is a rotating platform which serves as the mounting base for the system optics, samples, experiment-specific packages, and electronics. The optics plate will have components mounted on both the front and the back surfaces. To the back surface will be mounted components that generate the most heat (electronics, lasers, and computers). The front surface will be used to mount the experiment package, camera packages, and light delivery optics.

#### Mechanical Definition

SAR shall provide a surface which allows for the positioning of optical systems (cameras, light sources, and associated electronics), and procedures to reproducibly position and align the hardware and other experimental components located within the dedicated fluid physics volume. The relative positions of components shall be reproducible and knowable with the accuracy and precision required by the majority of basis experiments. The optics plate criteria is as follows:

- **Overall dimensions** – 89.5 cm × 119.4 cm (35.25 in. × 47 in.)
- **Mounting dimensions:**
  - Front: 70 cm × 100 cm (27.6 in. × 39.4 in.)
  - Rear: 84.5 cm × 116.8 cm (33.25 in. × 46 in.)
- **Top surface material** - Ferromagnetic stainless steel or Invar or aluminum alloy.
- **Top mounting options** – T-type rail design - 50 mm on center, the design is similar to milling machine table surface. This design will provide a slide mount internal to the optical table. M6 mounting holes will be provided at predetermined locations. The colored grid that is spaced every 25 mm (1 in.) is to be used as an index mark, and indentation points will be at the grid/slide intersection. Map-type identification labels will be on the table surface.

- Provide **electrical, data, and environmental interfaces** to support the facility and PI-specific hardware.

#### Optical/Structural Definition

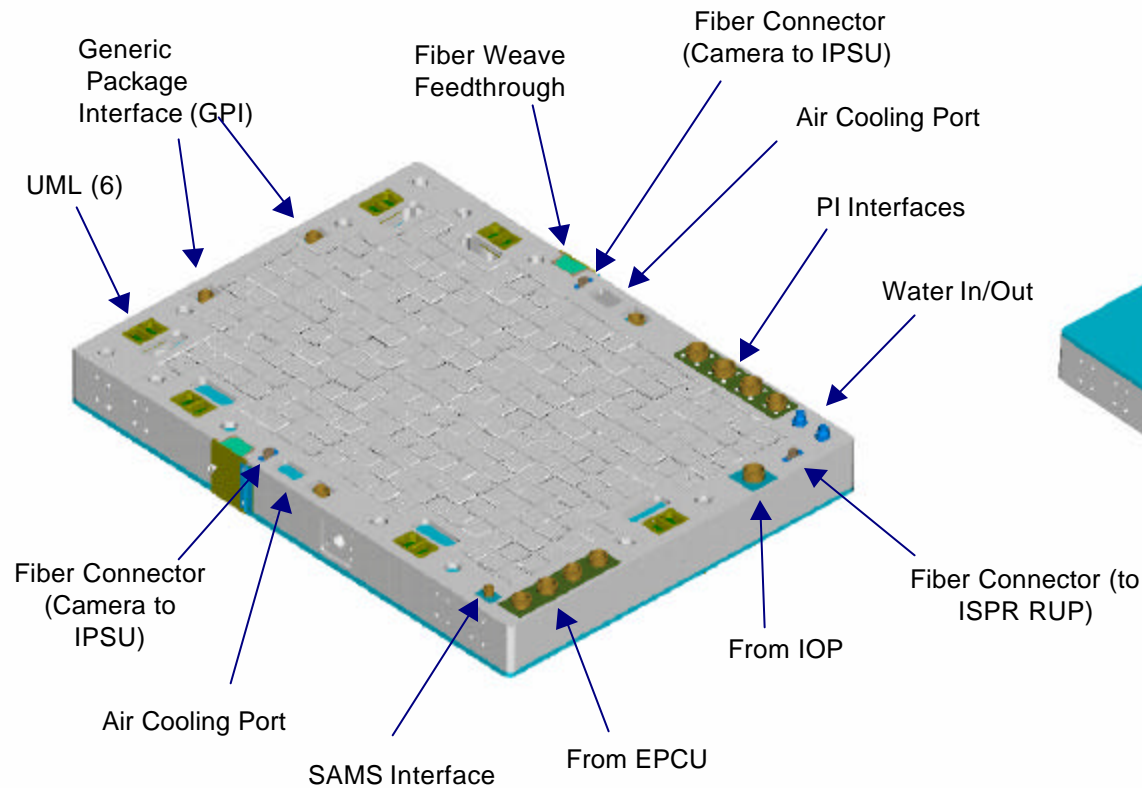
The optical requirements define the features and performance required to avoid degradation of optical measurements. Some of the following requirements also define structural requirements:

- Top flatness - p-p variation of < 0.5 mm
- Stiffness - TBD, Compliance < 1 μm / N
- First Harmonics > 100 Hz (bending and torsional modes). Must dampen normal modes of vibration.
- Top surface color Matte black (to minimize reflections)
- Isolate front plate from back plate
- Thermal Super Invar (Fe/Ni/Co alloy) may be used for the top surface skin, due to its low coefficient of thermal expansion and ferromagnetic properties

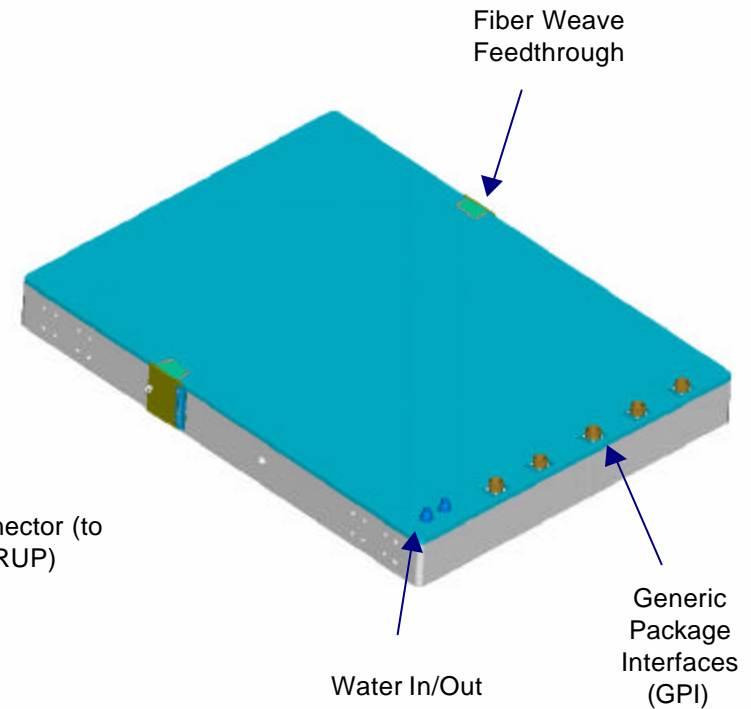
It is suggested that positions be measurable in a standard 6 degrees of freedom coordinate system (for example, x, y, z, θ, and so on). It is expected that any item installed in the facility by the crew on the optical bench will be *coarse-aligned to specific reference points, and that a mechanism for coarse-alignments (made by the crew) will be provided by the facility*. It is suggested that coarse alignment position coordinates (relative to a standard reference point) be reproducible and knowable with an accuracy of 2 mm (0.08 in.) and 2 degrees if the PI experiment and hardware both require and support such accuracy.

*The science interfaces available to an experiment on the Optics Bench Assembly are shown in the figure on the following page.*

## SAR Optics Bench Assembly Science Interfaces



Optics Bench Front  
(Science)



Optics Bench Rear  
(Science Support)

### C.2.3.2.2 Optics Plate Configuration Options

#### Mounting Locations

The design of the optics plate will provide for infinite mounting positions. The optics plate will have 8 (4 front, 4 back) generic package interface (GPI) connectors for diagnostics packages. Any SAR diagnostics package can be connected to any GPI without the need for additional cable reconfiguration by the astronaut. Additional interfaces on the front of the optics bench are provided for PI-specific connections to the Fluids Science Avionics Package (FSAP).

#### Mechanical Connections

An off-set cam lock-type lever will secure a spring loaded ball bearing slider plate to the optics bench. The various optical packages will either have the slider plate designed into the housing or will be attached to the slider plate with an L-type bracket of some sort. The back of the optics plate will accommodate this type of mounting to allow for the stowage of the SAR provided components. The use of this design allows for the crew to attach and position components without the use of any hand tools.

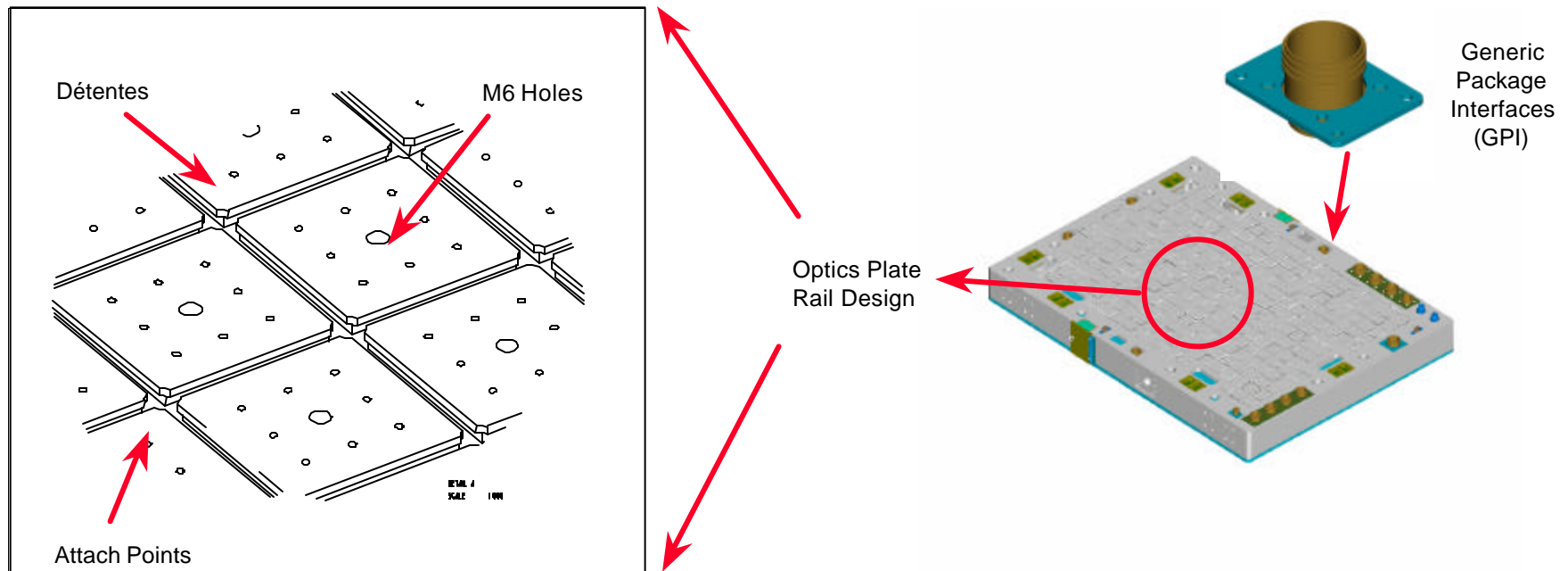
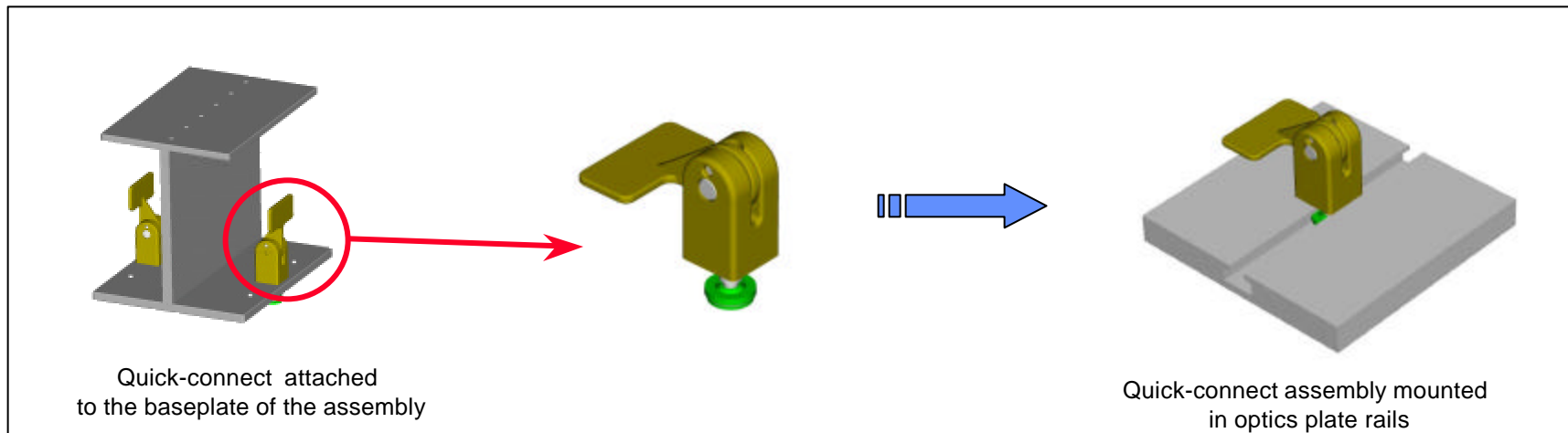
At the center of several of the optical bench's squares are standard M6 holes. These holes will allow for the attachment of large PI-specific hardware not requiring accurate positioning at the optics plate.

#### Electrical Connections

The optics plate has 20 electrical connectors for connection of diagnostics packages. These connectors are TBD-type (part # TBD) with electrical and fiber contacts. The connectors are arranged around the perimeter of the plate. A short (replaceable) cable harness connects the diagnostics package to the nearest Generic Package Interface (GPI).

*The quick-connect assembly concept and the rail design of the optics plate is shown in the figure on the following page.*

## SAR Optics Bench Quick-Connect Concept



### C.2.3.3 Science Avionics

Utilizing a suite of cameras, lenses, configurable mirrors, and ancillary support equipment, the SAR science avionics packages provide a flexible and feature-rich environment for acquiring high-quality digital video images.

The Fluids Science Avionics Package (FSAP) is a flexible, multi-purpose data acquisition and control system that is used to provide the capability to interact effectively with a wide range of fluids experiments. The FSAP provides a standard set of analog and digital I/O, motion controllers, analog video acquisition, data storage, and communication connectivity. It is flown up with the rack and stays on-orbit for use by PI experiments.

An Image Processing Storage Unit (IPSU) will provide an interface for acquiring data from digital cameras in real-time. Each IPSU is designed to support image acquisition for specific digital cameras in the imaging packages. Each IPSU will interface with its respective camera for digital data acquisition and with the FSAP for command and control. The Image Processing Package consists of two (2) IPSUs. The IPSU will store video data in a digital format. The data acquired will be compressed (if required) to reduce memory and transfer bandwidth and processed to support closed loop control scenarios such as focusing, zoom, and tracking. The dimensions of an IPSU are 290 mm x 224 mm.

*The science avionics packages that are available to SAR experiments initially on-orbit are shown in the following figure.*

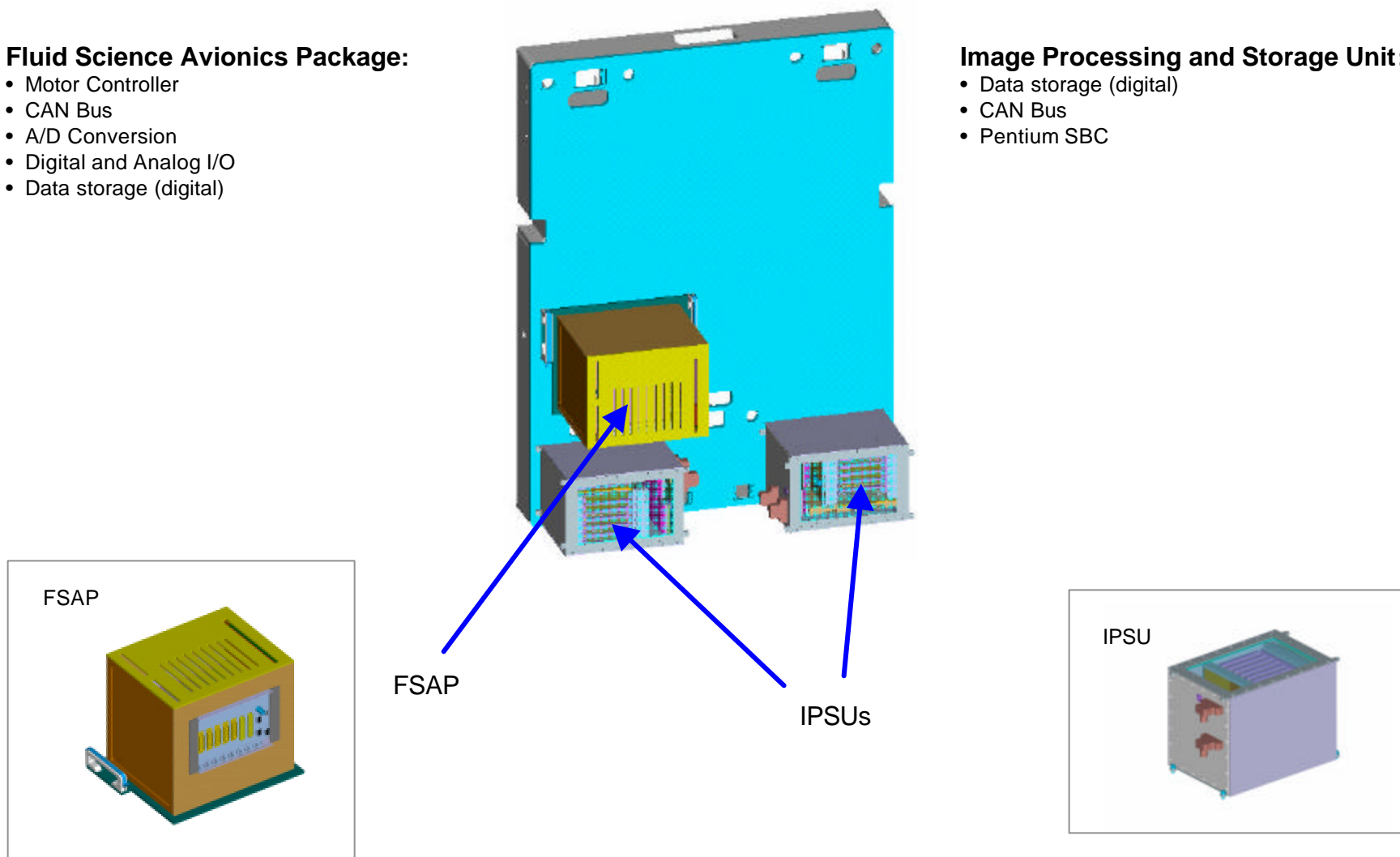
## SAR Science Avionics

### Fluid Science Avionics Package:

- Motor Controller
- CAN Bus
- A/D Conversion
- Digital and Analog I/O
- Data storage (digital)

### Image Processing and Storage Unit:

- Data storage (digital)
- CAN Bus
- Pentium SBC



#### C.2.3.4 SAR Middeck Locker Accommodations

The SAR can accommodate up to 4 single middeck lockers or two double middeck lockers on the optics plate. Each single locker provides approximately two cubic feet of storage volume. Equipment or PI-experiment hardware can be stored within these lockers which would be controlled thermally by the air circulated within the SAR. Power and data connections on the optics plate are available for conducting science experiments within the locker. The inside dimensions of a single size locker are: 25.3 cm x 44.0 cm x 51.6 cm.

Mounting holes are conveniently placed on the optics plate mounting surface. T bolts in slots on 50 mm centers can also be used to mount lockers.

Connectors around the perimeter of the optics plate provide the following services to the lockers:

- Air for natural or forced convection cooling
- Quick disconnects for water cooling to 500 watts
- Two fiber connections to IPSUs
- 4 electric power connections
- 20 connectors with electrical and fiber contacts for connection of diagnostic packages
- 8 generic package interface connectors for diagnostics packages
- 4 PI interface connectors

*The SAR configuration with four middeck lockers is shown in the figure on the following page.*

## SAR Configuration with Four Middeck Lockers

### Power

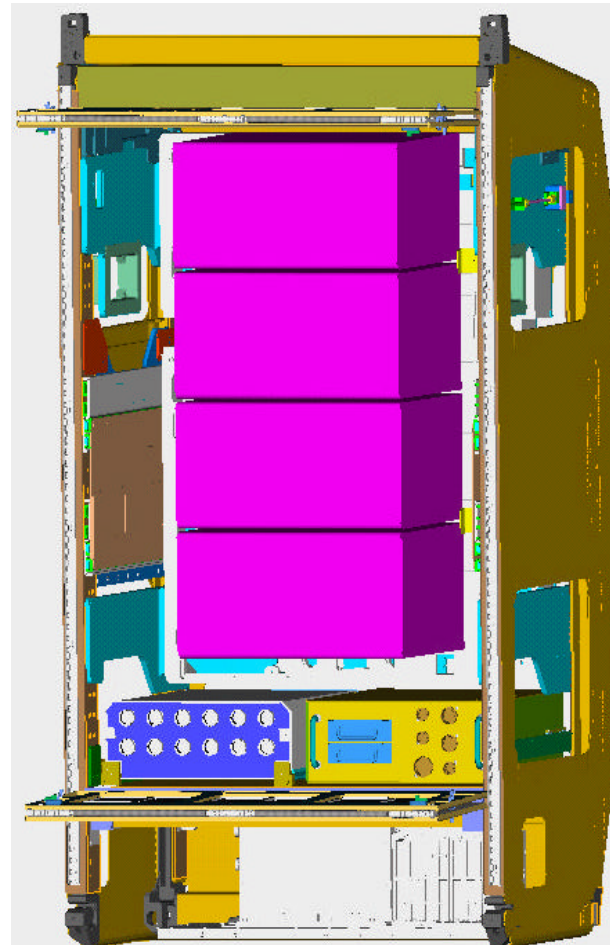
- Eight 28 VDC outlets

### Thermal

- 500 W air cooling
- 500 W water cooling

### Vacuum/vent/gas

- 1 VES
- 1 VRD
- 1 N2



### Data Interfaces

- Two RS422
- 8 Analog
- 12 bi-directional discretes

### Ethernet

- Two connections
- Two 1553B connections

### Video

- Two RS170 connections
- Receive 8 image streams from CIR/FIR

### Display NTSC Quality Video on Laptop

- 1024 x 768 lines
- 25 cm diagonal

### C.2.3.5 SAR Shared Resources Concept

One of the SAR functions is to provide additional resources to the FIR and CIR. The additional resources that can be provided by SAR are defined by the interfaces with FIR and CIR and the space available on the optics plate.

The usable space on the SAR optics plate is approximately 70 cm by 100 cm by 50 cm deep.

The available resources within SAR for the shared hardware are listed on Figure TBD.

IPSUs (Image Processing and Storage Unit) have been proposed as an additional resource to be shared with both FIR and CIR and are typical of the way a shared resource would be used. The shared accommodations concept shows two Image Processing Packages (IPPs), also referred to as double or stacked IPSUs, with two middeck lockers in place. IPPs were designed to conserve space and weight and consist of the two IPSUs.

Each IPSU on the SAR provides an interface for acquiring data from one digital camera in real time. The camera and IPSU are controlled by the FSAP. The IPSU will store video data in a digital format. The data can be compressed to reduce memory and transfer bandwidth. Data can be processed to support closed loop control such as focusing, zoom, and tracking. Each SAR IPSU enables one more camera to be used in FIR or CIR.

The Middeck Lockers shown with the shared resources concept can be used for storage or for experiments when the FIR or CIR are not operating.

*The SAR shared resources concept is shown in the figure on the following page.*

## SAR Configuration with Two Middeck Lockers and TWO IPSUs

### Power

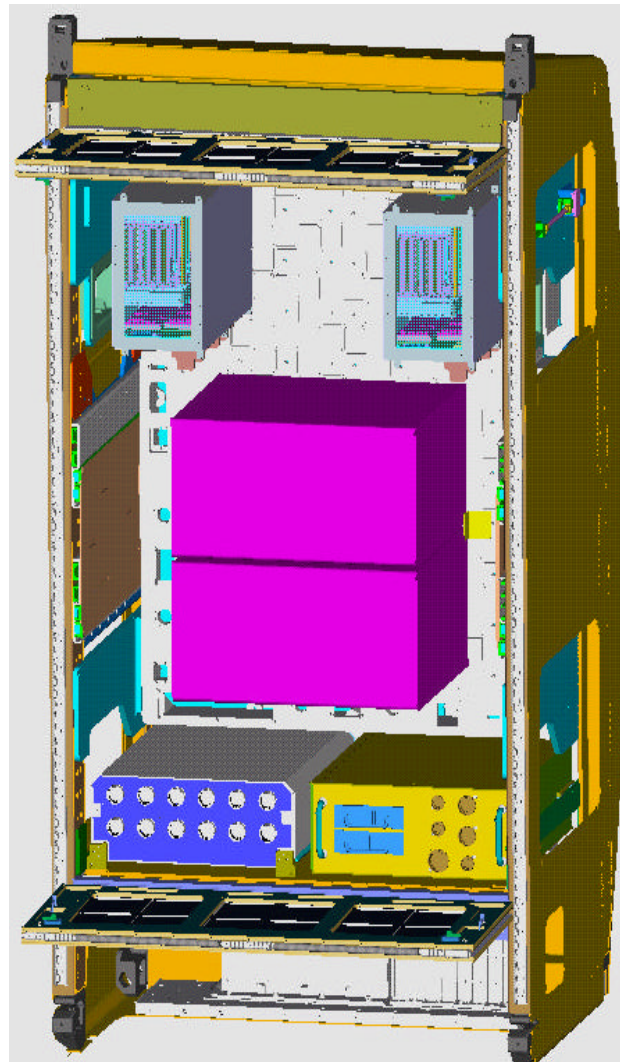
- Eight 28 VDC outlets

### Thermal

- 500 W air cooling
- 500 W water cooling

### Vacuum/vent/gas

- 1 VES
- 1 VRD
- 1 N2



### Data Interfaces

- Two RS422
- 8 Analog
- 12 bi-directional discretes

### Ethernet

- Two connections
- Two 1553B connections

### Video

- Two RS170 connections
- Receive 8 image streams from CIR/FIR

### Display NTSC Quality Video on Laptop

- 1024 x 768 lines
- 25 cm diagonal

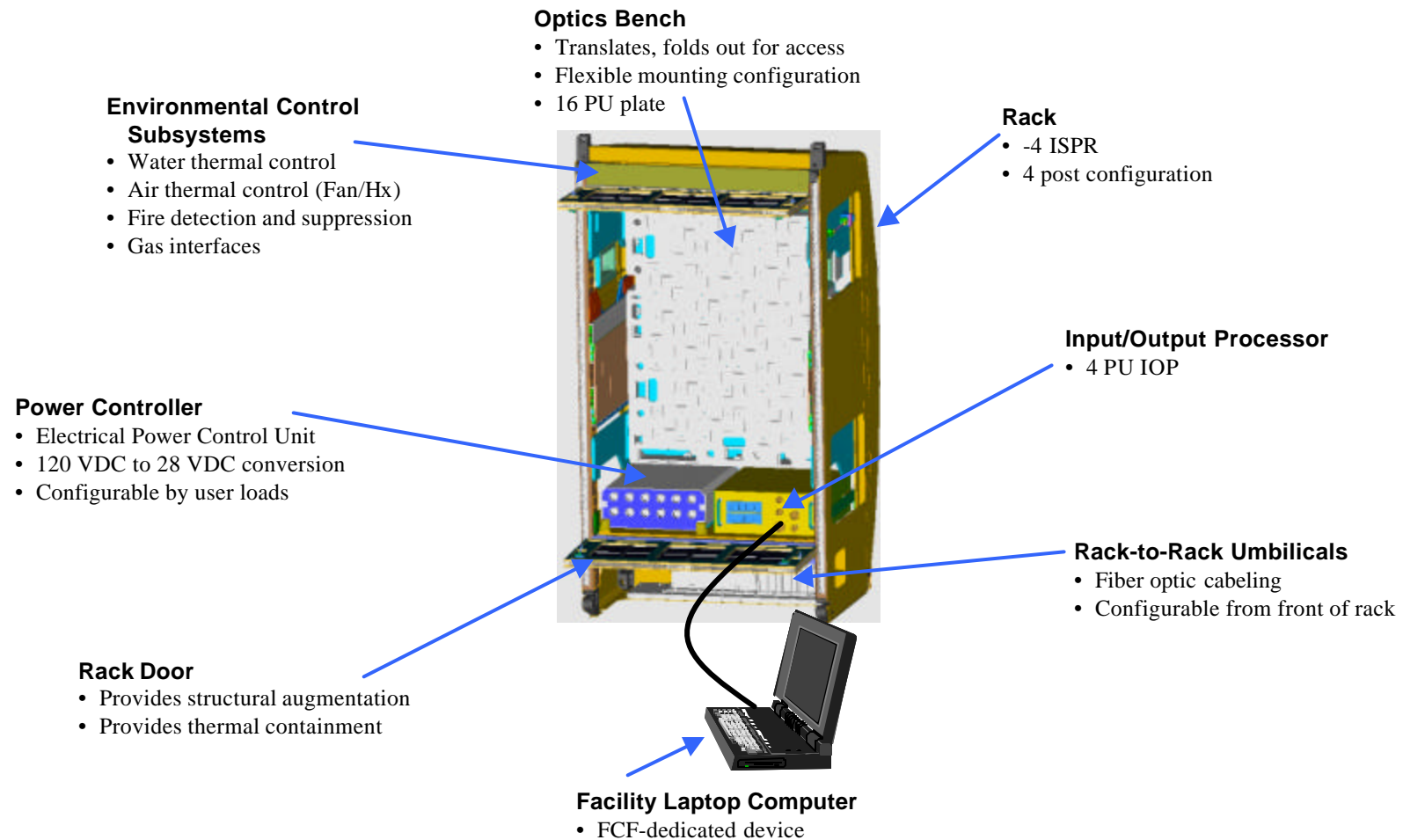
### C.2.3.6 Core Element

The SAR is supported by the following core science support subsystems:

- **Command and Data Management**
  - Command, data and image processing will be supported via a rack Input/Output Processor
  - Software utilizes embedded internet technology that is platform independent
- **Electrical Power Distribution**
  - Power distribution will be performed via an Electrical Power Control Unit
- **Environmental Control**
  - Air/Water heat exchanger utilizing hybrid water air heat rejection system
  - Smoke Detection/Fire Suppression
  - GN<sub>2</sub> ,Vacuum Vent, and Vacuum Resource interfaces
- **Structural**
  - Rack stiffening and strengthening
  - Rack closure doors
- **Active Rack Isolation**
  - Isolates rack from external microgravity disturbance

*The FCF SAR overview is shown in the figure on the following page.*

## FCF Shared Accommodations Rack Overview



**Power, Data, Environmental Control, and Structural Subsystems in SAR  
patterned after those in FCF Combustion Rack and FCF Fluids Rack**

#### **C.2.3.6.1 SAR Command & Data Management Subsystem**

The FCF SAR Command and Data Management System (CDMS) includes all hardware and software to provide command, control, health and status monitoring, data acquisition, data processing, data management, timing and crew interface functions. The CDMS interconnects the Input/Output Processor (IOP), Fluids Science Avionics Package (FSAP), Image Processing and Storage Units (IPSUs), and the PI science packages. The CDMS also consists of a crew interface via the Space Station Support Computer (SSC) and command, data, and video interfaces to the ISS Command and Data Handling System.

The functions of the major CDMS components are displayed in the following chart. Primary features of the CDMS include Ethernet, avionics CAN bus, PI CAN bus, analog and digital video routing, time synchronization, Sync bus, data storage and PI interfaces.

Ethernet communication is established between packages utilizing the Ethernet switch in the IOP. The IOP, FSAP, IPSU, SSC and PI hardware are connected with each other and ISS via the switch. Several functions are accomplished over Ethernet, including:

- Command and control of the FSAP and IPSU
- Inter-process communication between the FSAP and IPSU, and between the FSAP processors
- Transmittal of PI hardware health and status acquired by the FSAP
- Data file transfer, including software upgrades, video, and science data, between the IOP and FSAP, IPSU, SSC, and PI hardware
- Time synchronization

*The following figure shows the SAR avionics subsystems.*

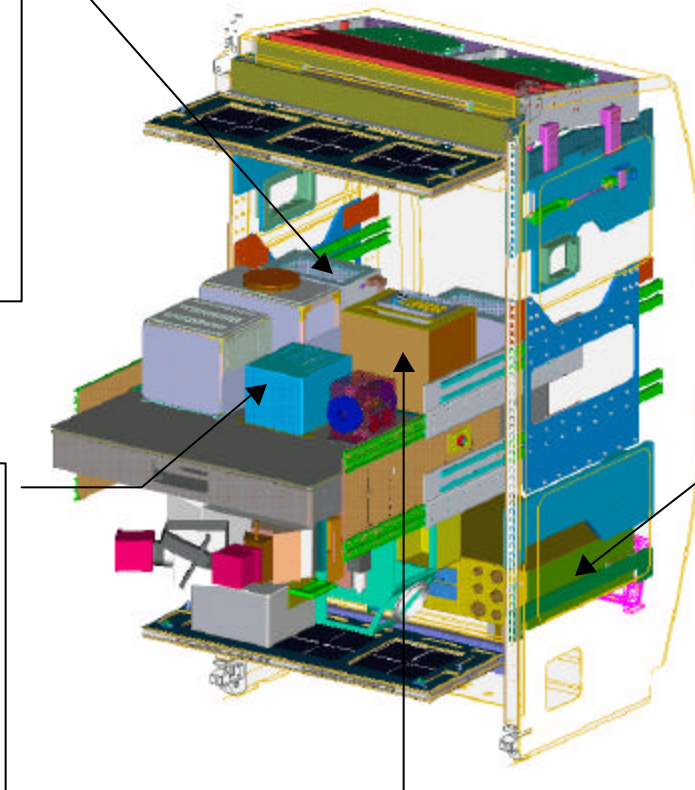
## FCF SAR Data Acquisition Functions

### IPSUs

- Two Independent Image Processors
- Digital Camera Ready
- COTS Compact PCI Bus Technology
- Hard Drives (Qty. 4)
- Motion Control for APT/Focus/Zoom
- Ethernet / Serial Communications

### FSAP

- Real Time Data Acquisition and Control
- Color Camera Support
- COTS Compact PCI Bus Technology
- Hard Drives (Qty. 2)
- Ethernet / Serial Communications
- Digital and Analog I/O
- Motion Control
- Ready to Accommodate Science Specific Hardware



### IOP

- HRDL, MRDL, 1553B Station Interface
- Ethernet, 1553, Serial Intra-rack Communications
- PFM Video Interface (CVIT)
- Supervisory Control & Data Acquisition
- Removable Hard Drives (Qty. 2)
- Time Server and interface to ISS timing
- Health and status collection

### C.2.3.6.2 SAR Electrical Power Subsystem

#### SAR Power Components

The FCF SAR Electrical Power Subsystem (EPS) consists of an Electrical Power Control Unit (EPCU), cables from ISS to the EPCU, harnesses from the EPCU to PI/facility loads, PI/facility load converters, a 1553B interface between the EPCU and IOP, a Rack Maintainance Switch Assembly (RMSA), an EPCU Shutoff Switch Assembly (ESSA), and Rack Door Limit Switch..

#### SAR Power Distribution

120 VDC is applied to the input of the EPCU. The EPCU provides a quantity of six 120 VDC, 4 Amp and forty-eight 28 VDC, 4 Amp output channels. One 120 VDC channel is routed to the FDSS and ARIS each. Three 120 VDC channels are routed to the PI 120 VDC power connector on the front left side of the rack. Of the forty-eight +28VDC channels, three are routed to the IOP, four are routed to the ECS, and twenty-eight are routed to the optics bench for avionics, diagnostic, and PI use. Of the 28 channels to the optics bench, eight are available for PI use.

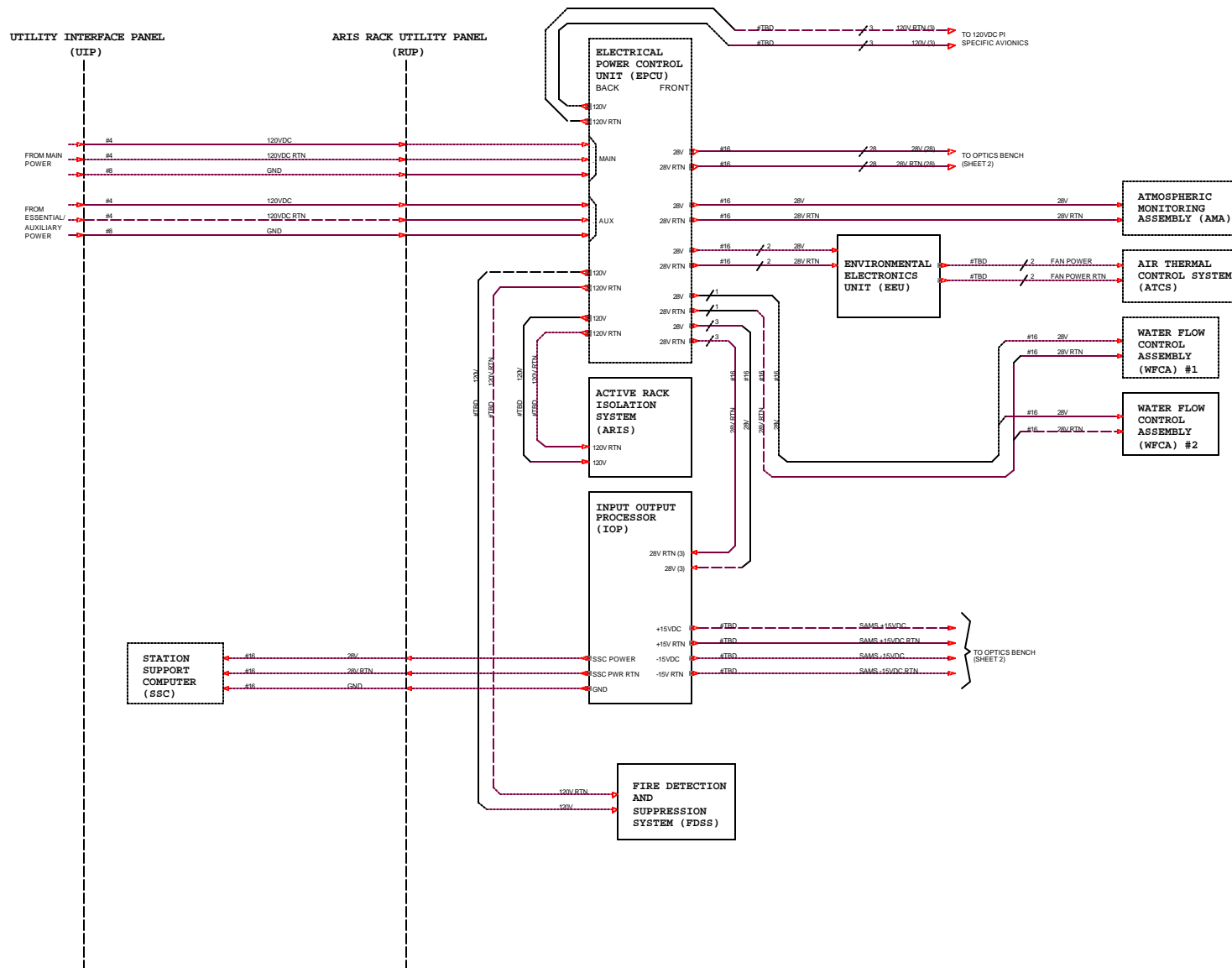
#### SAR Bonding and Grounding

Grounding of each package in the SAR is accomplished utilizing a ground wire electrically connecting the package enclosure to rack structure and/or an electrical bond through the package faying surface to the rack structure. Each package not on the optics bench is electrically bonded to the rack structure via its faying surface and mounting to the rack. The optics bench is electrically bonded to the rack structure via a bond strap connected to a rack post. Packages on the optics bench are electrically bonded to the optics bench via the contact between their faying surfaces and the surface of the optics bench, or by the contact of their faying surfaces to other package surfaces, which are bonded to the optics bench. In addition, all packages on the optics bench are grounded utilizing a ground wire. Ground wire contacts in the input power connector of each package are electrically connected to the package structure. The input power connection to the optics bench contains a ground wire, that is electrically connected to the bench.

The ground fault current path is then from the package enclosure, through the ground wire, to the optics bench, through the bond strap, to the rack post, to the EPCU. Each ground fault current path is capable of handling the maximum fault current that is possible.

*The following figure depicts the SAR power distribution.*

## Shared Accommodations Rack Power Distribution Block Diagram



#### **C.2.3.6.3 SAR Environmental Control Subsystem**

The Environmental Control Subsystem (ECS) performs thermal control, fire detection, fire suppression, and gas distribution functions associated with the operation of the FCF SAR. Each of the ECS functions is performed by the following distributed science support systems.

##### **Water Thermal Control System (WTCS)**

The WTCS removes waste thermal energy generated by SAR systems. Thermal energy is removed directly through cold plates or indirectly through a forced convection air system. The thermal loads are rejected to the ISS Internal Thermal Control System (ITCS) using the U.S. Lab Module Moderate Temperature Loop (MTL) water as the medium for thermal transfer. The WTCS will be designed to remove up to 3.0 kW of waste thermal energy from the SAR.

##### **Air Thermal Control System (ATCS)**

The ATCS removes waste thermal energy generated by the SAR systems using the ISPR internal atmosphere as the medium for thermal energy transfer via an air/water heat exchanger. The ATCS rejects heat to the ISS MTL via the WTCS. The ATCS will be designed to provide the FIR with nominally 1500 Watts of avionics air-cooling. Preliminary analysis indicates packages and assemblies will be supplied with cooling air ranging from 28°C to 40°C (82°F to 104°F).

##### **Fire Detection and Suppression System (FDSS)**

The FDSS senses the presence of particulate products of combustion in the ISPR internal atmosphere and provides an alarm signal to the Space Station. The FDSS provides accommodation for discharge of fire suppressant from the Space Station Portable Fire Extinguisher (PFE) into the internal volume of the SAR ISPR.

##### **Gas Interface System (GIS)**

The Gas Interface System (GIS) provides the Fluids Element and Experiments access to ISS Gaseous Nitrogen, Vacuum Resource, and Vacuum Exhaust services. The SAR has an independent GIS to facilitate distributed access. The GIS interface panel provides a crew-accessible panel that allows the SAR experiments to access the ISS resources. This arrangement facilitates a variety of configurations optimizing use of the ISS Gaseous Nitrogen and Vacuum Exhaust services.

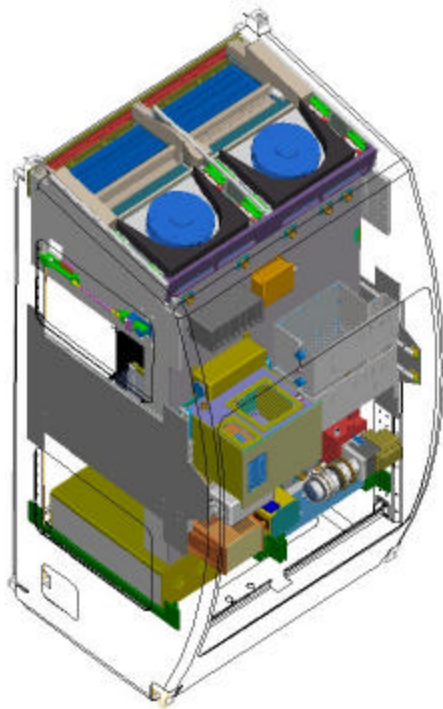
*An overview of the SAR Environmental Control System is shown in the following figure.*

## FCF SAR ECS Description

### Air Thermal Control System

Blower(s), 200 CFM @ 0.4 inches to 0.6 inches water

- Air/water Heat Exchanger, 1500 watts
- Filter



### Gas Interface System

- Direct hookup to PI hardware
- Controlled via IOP

### Smoke Detection System

- Station Supplied Smoke Detector
- Can be monitored by both SAR and ISS

### Water Thermal Control System

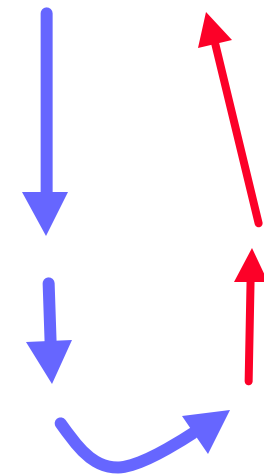
- MTL Interface
- Bulk SAR Heat Rejection up to 3.0 Kw

### Optics Bench Direct Water-cooling

- Direct Water Hookup for PI Hardware
- 500 Watts (nominal) Cooling Capability

### Fire Suppression System

- Pressurized CO<sub>2</sub> Canisters
- Manually injected into the front of the SAR



### **SAR Gas Interface System**

The SAR GIS interfaces with the Space Station gas services at the Utility Interface Panel (UIP). These services are routed to the Rack Utility Panel (RUP) using ARIS provided flexible umbilicals.

The PI-Experiment interface with the GIS is at the Gas Interface Panel (GIP). The GIP is mounted on the left side wall of the SAR. The GIP contains one quick-disconnect (QD) each for GN<sub>2</sub>, Vacuum Resource, and Vacuum Exhaust services. Flexible umbilicals interconnect all hardware elements with the GIP.

The GN<sub>2</sub> line contains a manually operated shutoff valve to provide rack level isolation. The Space Station controls rack level access to the Vacuum Resource and Vacuum Exhaust systems with isolation valves in the standoffs.

Pressure regulation, flow control and exhaust gas processing functions are allocated to the SAR hardware elements interfacing with the GIS.

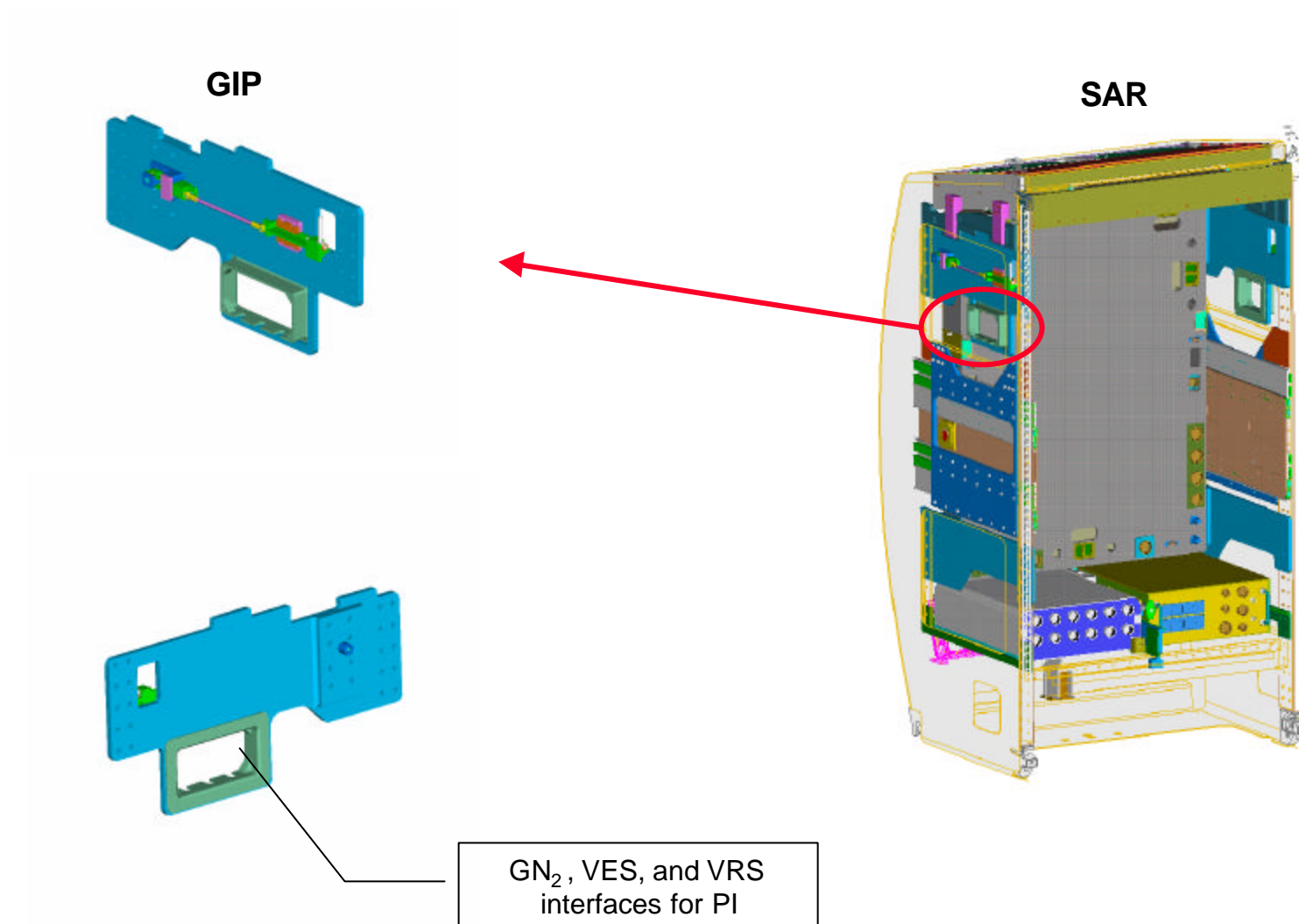
SPOE connectors will be used for the interfaces at the UIP and the RUP.

For pressurized systems, the hardware is designed to comply with specific requirements other than fault tolerance. It must meet fracture control requirements and factors of safety listed in NSTS 1700.7, its addendum, MIL-STD-1522A, and NASA-STD-5003. This approach is generally not advisable for items that change configuration on-orbit since the original ground verification only applies to unmodified hardware. The SAR will need to demonstrate that the flexible umbilicals, if under pressure, will not break free and flail about.

The PI will also have to verify that what is being vented complies with the acceptable materials list and is compatible with the station hardware. The PI hardware that interfaces with the Vacuum Exhaust System (VES) is limited to 40 PSIA. If the pressure is expected to be greater, the PI must provide a pressure regulator.

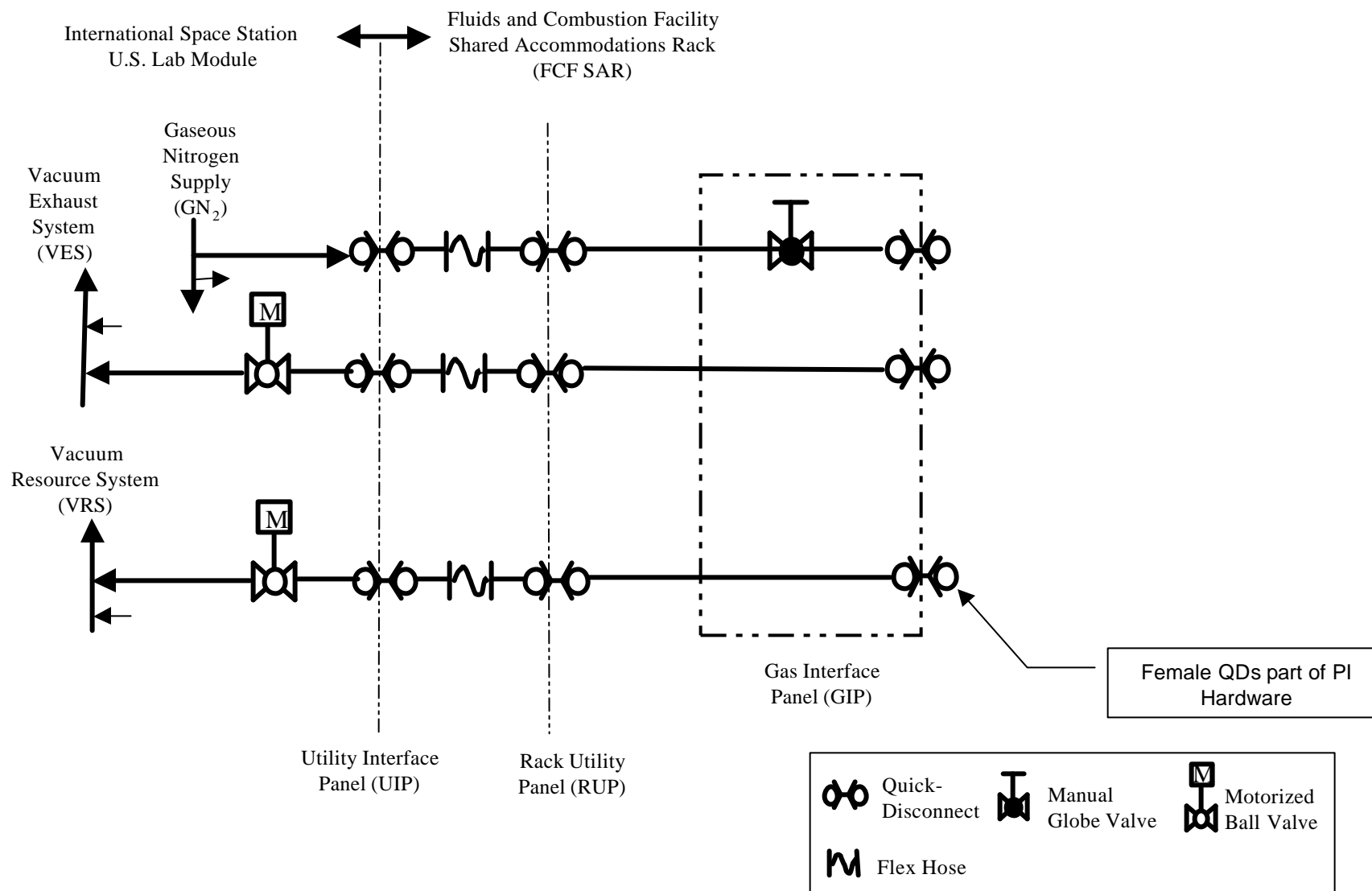
*A schematic of the Gas Interface System (GIS) is shown in the following figure.*

## FCF FIR/SAR Gas Interface Panel (GIP)



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## Gas Interface System Schematic



## C.2.4 SAR Metrics

### Mass Summary

The following table details the estimated mass of each SAR subsystem. The table lists all of the subsystems that will be needed for on-orbit operation as well as the subsystems that will be installed when launched to the ISS. Additional information can be found in the *FCF Mass Properties Report* (FCF-RPT-0061).

All of the SAR diagnostic packages will be stowed in foam lined re-supply lockers for launch. This will minimize environmental testing of the packages which will reduce development costs and enable the project to use COTS for many of these components. To minimize crew time for the installment and reconfiguration, these components have an integral quick latch mechanism that allows for easy installation and removal.

*The following figures show the SAR Mass Summary for launch and on-orbit configurations.*

## FCF SAR Mass Estimates for Launch and On-orbit Configurations

	Assembly	Base Mass [KG]	Percent of Total	Installed During Launch ?	Installed During Operation ?
SAR Unique Hardware	Optics Bench Assembly (includes optics bench, Support Plates, and Seals)	141.87	17.82%	Y	Y
	Atmospheric Monitor Assembly	2.30	0.29%	N	Y
	FSAP	15.83	1.99%	Y	Y
	MISC. (VRS Interface)	5.00	0.63%	Y	Y
Common Hardware	IPSUs (QTY. 2)	15.64	1.96%	Y	Y
	RACK DOORS	25.00	3.14%	Y	Y
	Pin Assemblies	5.95	0.75%	Y	Y
	Rack Misc Structures (center post & attachment HW)	10.573	1.33%	Y	Y
	I/O Processor	24.70	3.10%	Y	Y
	Stowage Items (hard drives for IOP)	4.44	0.56%	N	Y
	Slides (includes Rotational & Brake Assemblies)	48.54	6.10%	Y	Y
	ECS - Water Distribution & Control Assy	32.54	4.09%	Y	Y
	ECS-ACCUMULATOR ASSEMBLY (removed on-orbit)	1.80	0.23%	Y	N
	ECS - Air Thermal Control Assembly	44.64	5.61%	Y	Y
	Gas Interface System Assembly	16.23	2.04%	Y	Y
	Fire Detection & Supression Assy	2.47	0.31%	Y	Y
PI	Experiment Assembly -(Service Umbilical Set + ESSA)	6.48	0.81%	Y	Y
	PI Experiment Package (includes Middeck Locker Mounting Assembly)	131.00	16.45%	N	Y
GFE	ARIS - Launch Condition*	61.06	7.67%	Y	Y
	ARIS - Additional On-Orbit Mass*	14.45	1.81%	N	Y
	EPS - EPCU Assembly	48.53	6.09%	Y	Y
	EPS-EPCU Umbilicals	2.84	0.36%	Y	Y
	EPS-RMSA	0.64	0.08%	Y	Y
	Rack - Rack Assembly	111.90	14.05%	Y	Y
	Rack-Rack to Station I/F umbilical set (ARIS)	10.66	1.34%	N	Y
	SAMS Subsystem	1.23	0.15%	Y	Y
GROSS TOTALS		786.31	100%		
Integrated Rack Limit		804.20			

\*For additional details on mass estimates, see FCF-RPT-0061

## Power Estimates

Power estimates (worst case) for the SAR subsystems are presented in the following table. The estimates include the typical and maximum power consumed by each subsystem for both the 28 and 120 VDC supplies. Further details can be found in TBD.

*The following table details the SAR subsystem power estimates.*

## SAR Subsystems Power Estimates

### Maximum Process Scenario (8 channels)

Hardware Assembly					Power Estimates			
					Typical @ 28VDC AIR (Watts)	Typical @ 28VDC WATER (Watts)	Typical @ 120VDC AIR (Watts)	Typical @ 120VDC WATER (Watts)
Core Elements			IOP		160	0	0	0
			ECS		176	0	3	0
			ARIS		0	0	41	72
			SAMS FF		2	0	0	0
			SSC		39	0	0	0
			AMA		2	0	0	0
Shared Elements	Science Support Packages	Avionics	FSAP Main Section		140	0	0	0
			Common IPSU (2 per)		300	0	0	0
		Image Processors	Double IPSU #1		300	0	0	0
			Double IPSU #2		300	0	0	0
			Double IPSU #3		300	0	0	0
	Science Specific Packages		PI	Air Cooled	500	0	0	0
				Water Cooled	0	0	0	0
		Subtotal			2219	0	44	72
		Cable Losses (2%)			45	0	1	1
		Subtotal			2264	0	45	73
		EPCU			272			
		Total Power (Typical)			2655			

\*For additional details on power estimates, see FIR-RPT-0164

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## **Appendix C.3 Shared Accommodations Rack Utilization and Operations**

## C.3 Utilization and Operations

### C.3.1 SAR/PI Hardware Integration

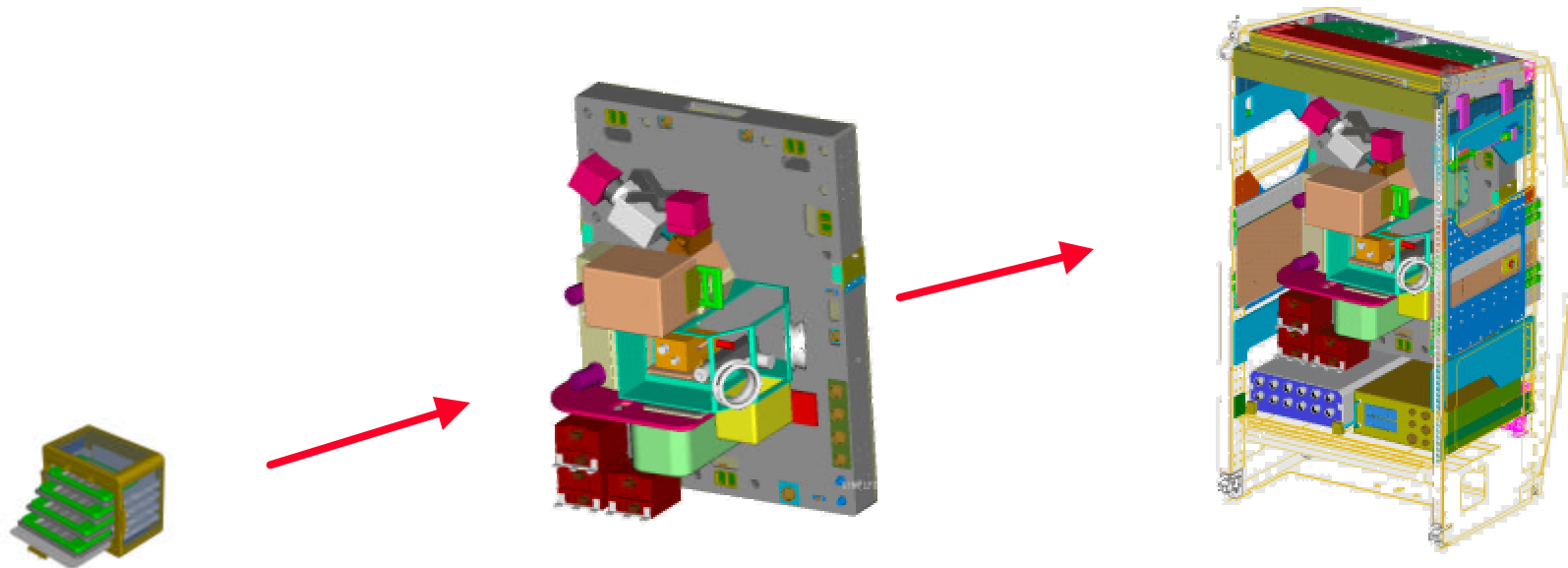
The SAR features the capability to remove and replace different PI-specific Experiment Packages (EPs). The PI experiment specific package(s) may consist of a single self-contained unit and/or several separate components. The PI hardware will typically be a unique design, but may re-use hardware and designs from previous experiments. A set of similar experiments investigating common phenomena and/or using similar diagnostics may permit the development of a “mini-facility” that can accommodate multiple PIs to significantly lower overall PI development costs. The experiment package will typically consist of the fluids test cell(s), precision optical diagnostic instrumentation (shearing interferometry, schlieren, surface profilometry, and so on) that interface with SAR services previously discussed, and any support equipment such as injection and mixing devices, motors, critical temperature hardware, magnetic field generation, and so on.

The SAR is capable of accommodating many different sized experiment packages. Its design is intended to be flexible enough to accommodate most anything within the physical dimensions from the front of the optics plate to the ISPR door. However, the ISS provides resource allocations to the FCF that put some limits as to what SAR can accommodate. In the future, it is foreseeable that the typical allocation for a PI may increase, the SAR is designed with this in mind.

The LMM concept is designed to provide accommodations for the initial four fluids experiments already selected for flight on the FCF FIR. FIR-DOC-042 summarizes the current engineering interpretation requirements for the FIR/LMM. Since the SAR design is very similar to the FIR, the integration of PI-hardware to the FIR using the LMM concept is very indicative of how PI-hardware will be integrated to SAR.

*The integration of PI experiment hardware to the SAR is depicted in the figure on the following page.*

## FCF FIR/LMM Integration Concept



### PI-specific Hardware

- Samples with supporting hardware
- Specific Diagnostics
- Specific Imaging

### Light Microscopy Module (LMM)

- Test Specific Module
- Science Infrastructure (hardware/software) items that uniquely meet the needs of the P-2, Yodh, and Wayner PIs
- Unique Diagnostics
- Specialized Imaging
- Fluid Containment

### Fluids Integrated Rack (FIR)

- Power Supply
- Avionics/Control
- Common Illumination
- PI Integration Optics Bench
- Imaging and Frame-capture
- Fluid Diagnostics
- Environmental Control
- Data Processing
- Frangibles and Laser Light Containment

### C.3.2 FCF SAR On-Orbit Operations

The SAR has two primary functions: provide additional resources to the FIR and CIR; provide accommodations for SAR Science experiments. Operations for the SAR experiments is essentially the same as for the FIR and CIR experiments and is described in detail in the sections that follow. Operations support is required to implement the shared resources. Astronauts must install the hardware, typically avionics or diagnostics hardware, on the optics plate and make the interface connections to the FIR or CIR. The hardware is then an integral part of the FIR or CIR operations and the appropriate CDMS will be used to operate the hardware and conduct the experiment.

As with FIR and CIR, the SAR must accommodate a wide range of experiments having a broad variety in types of samples, types of measurements, and other experiment factors. In order to accommodate this wide variety of experiments, the SAR is modular; with its capabilities easily configured to the requirements of a particular experiment or series of tasks. Many off-the-shelf hardware components are integrated within the SAR including plug-in computer boards to maximize versatility and replicability of provided hardware for the interfacing scientist. The SAR allows the ability to raise scientific data quality and quantity while lowering per-experiment costs relative to other ways of performing such experiments.

Astronauts are required to execute experiments on the SAR. However, crew time available for on-ground training and direct experiment interaction aboard the ISS will be limited requiring simple procedures for crew intervention, minimizing crew observation of experiments and minimizing the need for the crew to make on-orbit decisions.

The SAR enables the Principal Investigator (PI) to participate directly in the control of their experiment through remote operation and direct observation. Observation provides the PI with experiment information, allowing assessment of performance and providing cues for automated and non-automated intervention. Ground based systems will enable scientist interaction with other researchers at other remote locations.

Operations will be primarily conducted from the LeRC Telescience Support Center (TSC). Remote PI sites will be provided with the necessary equipment to conduct operations.

The Ground Team at the TSC will monitor the experiment health and status and control the experiment operation. The PIs will control their experiments from the TSC or their remote sites by uplinking new test parameters through the TSC. Downlink Data will be stored at the TSC until it can be distributed to the PI site. The capability will exist to control the FCF SAR from a dedicated on-orbit laptop. The crew is not the primary FCF operator.

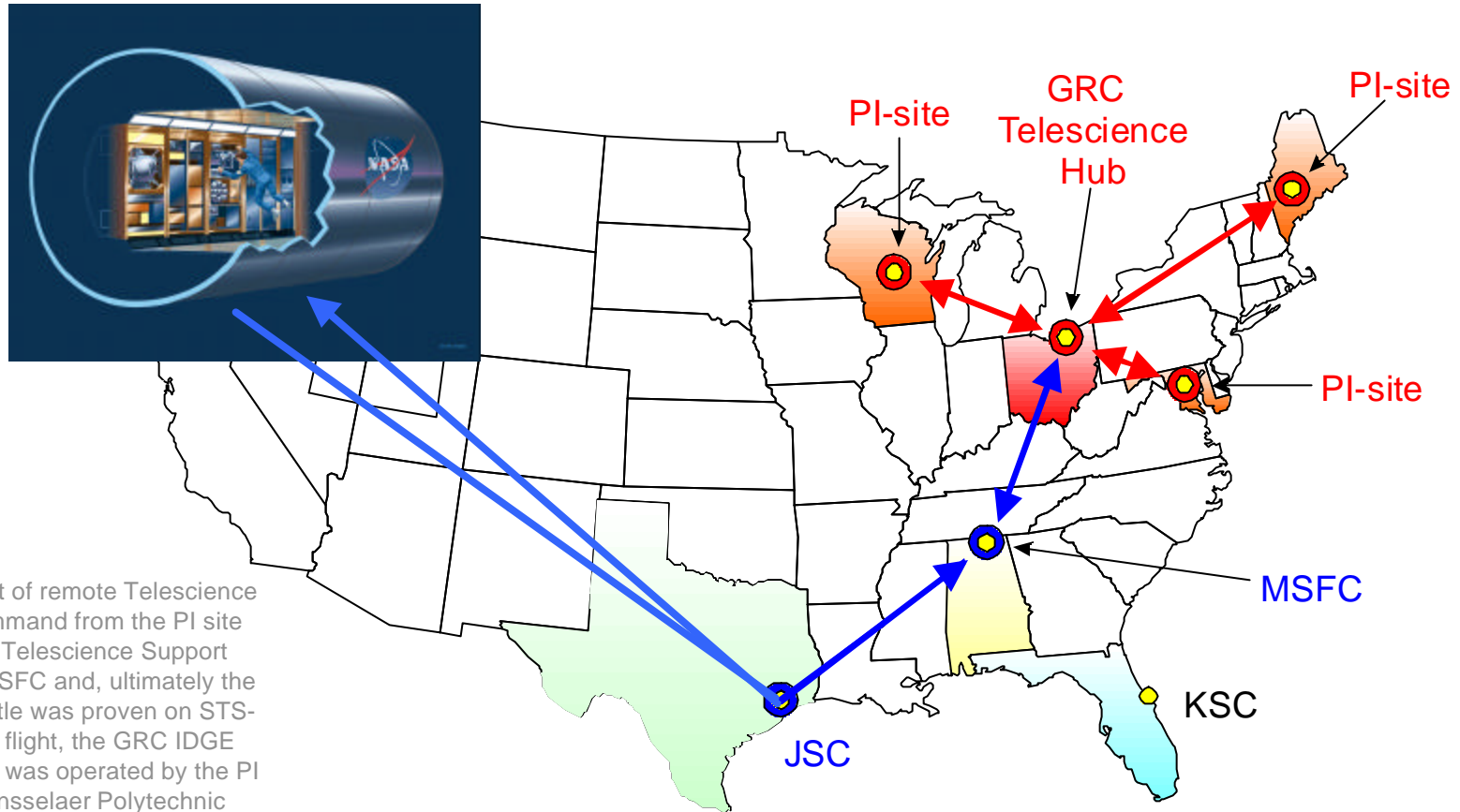
As with FIR and CIR, the SAR will limit its use of the Crew to experiment setup, reconfiguration, and maintenance. These activities are described as follows:

- **Setup** encompasses all activities required for initial experiment operations such as installing gas bottles and PI hardware.
- **Reconfiguration** involves moving diagnostics to new locations, refocusing, replenishing consumables, and so on.
- **Maintenance activities** consist of recalibrating or replacing sensors, replacing filters, and conducting scheduled maintenance.

*The FCF SAR Telescience Hub operations concept is shown in the figure on the following page.*

## FCF SAR Telescience Hub Operations Concept

ISS US Laboratory Module



The concept of remote Telescience with full command from the PI site through the Telescience Support Center to MSFC and, ultimately the Space Shuttle was proven on STS-75. On that flight, the GRC IDGE experiment, was operated by the PI from the Rensselaer Polytechnic Institute in Troy, N.Y.

### C.3.2.1 SAR CDMS Operations Overview

As with FIR and CIR, the SAR Command and Data Management System (CDMS) operates at multiple levels, with each level having its own tasks and responsibilities. Tasks for an experiment are broken down into three phases: the Pre-experiment Phase, the Experiment Run Phase, and the Post-experiment Phase.

#### Pre-experiment Phase

The SAR has two types of pre-experiment phase operations. One is associated with the SAR experiments and is similar to the pre-experiment phase for FIR and CIR experiments. The other is associated with the shared accommodations provided to either FIR or CIR. For SAR experiments the Pre-experiment Phase is the time when experiment hardware and software is uploaded, configured, aligned, calibrated, and so on. The Station Support Computer (SSC) and SAR IOP can be used to ready the rack hardware and software for specific experiment runs. The SSC provides the crew an interface for control and operation of the SAR and the experiments. For shared accommodations, the Pre-experiment Phase is the time when the hardware to be shared with FIR or CIR is installed on the optics plate and connected to the FIR or CIR interfaces.

#### Experiment Run Phase

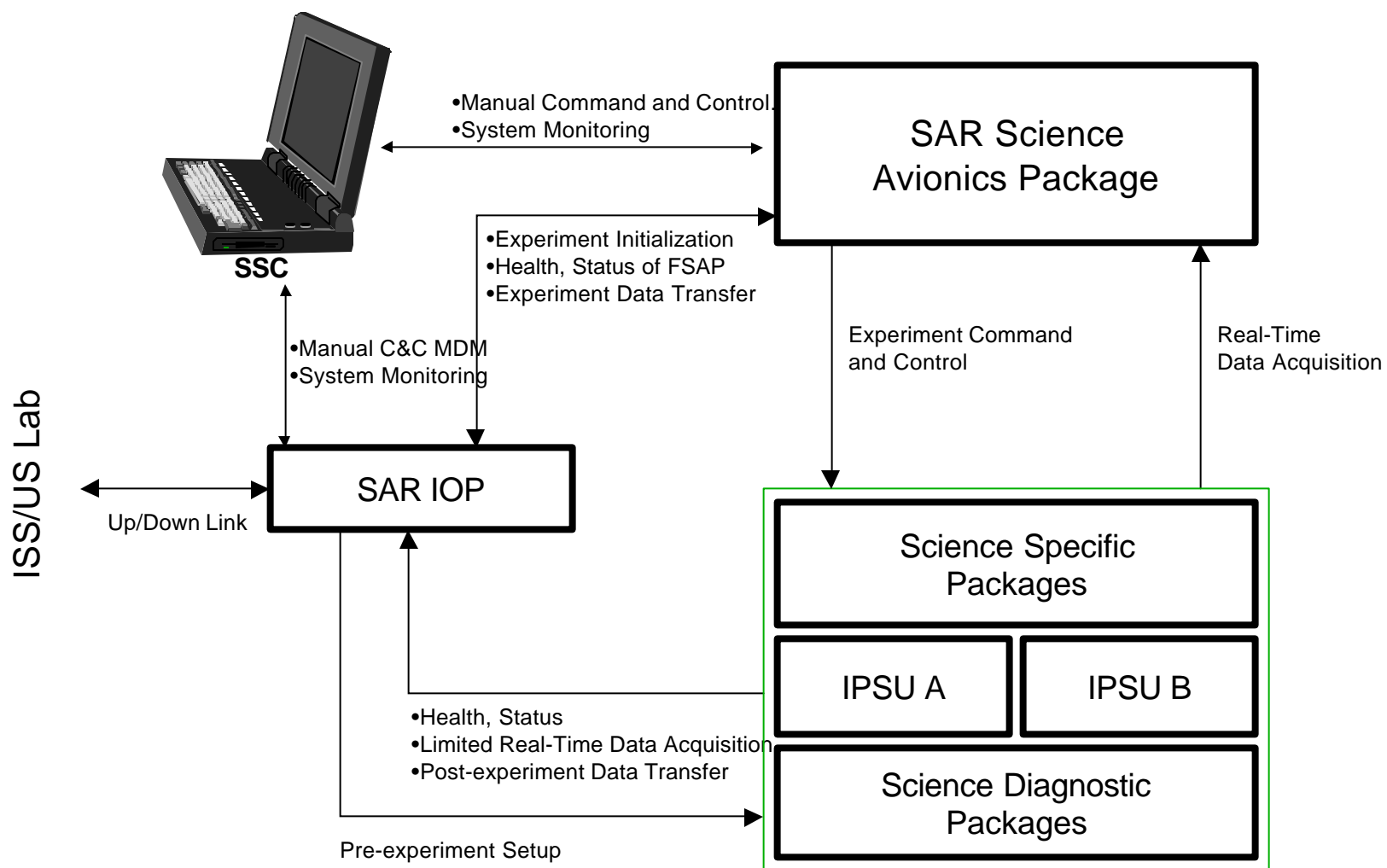
SAR experiment runs can be initiated from the SSC manually or remotely via the IOP. Once this phase is initiated, the FSAP performs the specific tasks required to perform the experiment. The IOP and SSC are used for health and status monitoring, as well as some limited passive data acquisition. The IOP also provides a timing signal to the FSAP for critical science data time stamping.

#### Post-Experiment Phase

After SAR experiment runs have been completed, science data is post-processed. This phase includes data compression, downlink, and any cleanup tasks that may be required. The Post-experiment Phase may be initiated remotely via the IOP, from the SSC, or automatically by the FSAP following the completion of the Experiment Run Phase. After FIR or CIR experiments with shared SAR accommodations have been completed the shared resources will be reconfigured for the next experiments.

*The Command and Data flow through the three phases of SAR operation is shown in the figure on the following page.*

## FCF SAR CDMS Operation



### C.3.2.2 SAR Set-up Scenarios

There are two types of SAR set-ups; one for SAR experiments and one for shared accommodations experiments.

#### C.3.2.2.1 SAR PI Experiment Set-up Scenario

The set-up operations for SAR experiments are essentially the same as FIR and CIR. Each new SAR experiment will require an astronaut to install and configure the diagnostics per the requirements of the particular experiment. When setting up a new experiment, the astronaut will first be required to fold open the FCF doors covering the un-powered SAR to gain access to the optics bench where the experiment will be configured.

Prior to experiment installation, if SAR standard diagnostics need to be reconfigured (experiment-unique) on the back side of the optics plate, the astronaut can gain access by retracting the pins (3 total) that secure the optics plate in its operational position. The optics plate may then be slid to its forward crew access position and locked in place. The astronaut will next activate the tilt mechanism designed to control translation of the optics plate to its extended position. The astronaut will then unstow/install PI-specific diagnostics/electronics and re-configure provided facility diagnostics. The tilt mechanism is again engaged to translate/fold the optics plate back to its upright experiment crew access position.

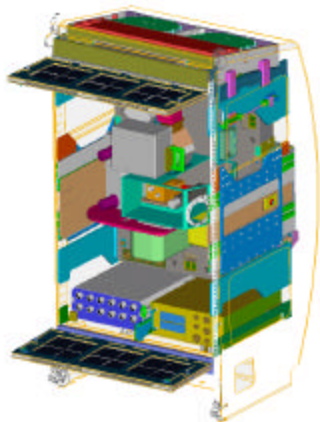
The astronaut will then unstow and install the PI-specific experiment hardware on the front of the optics plate. After installation and attachment of the major components to the optics plate, the astronaut will be required to connect the front interfaces and to provide rough alignment of diagnostics (precision alignment will be done autonomously from the ground). The optics plate is unlocked from its forward position and slid back to its operational position in the ISPR. The optics plate pins are engaged to lock the optics plate for operations.

The rack may be powered at this time in a minimal mode to do preliminary experiment checkout (ability for powered crew interaction is limited by thermal and safety constraints). Finally, the astronaut closes the door. Experiment startup can now be initiated either from the ground or by the crew via a laptop.

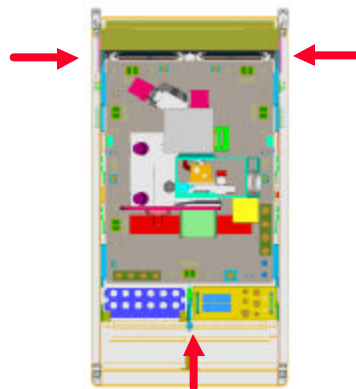
*A typical SAR experiment setup scenario is shown in the figure on the following page..*

## FCF SAR Nominal PI Set-up Scenario (1 of 2)

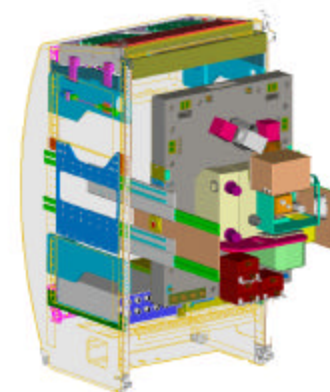
**Step 1**      **10 Minutes**  
Fold Open Doors



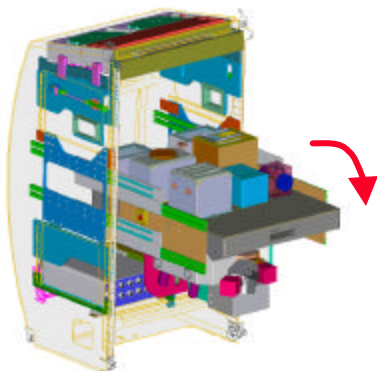
**Step 2**      **15 Minutes**  
Retract Pins  
(No Tools)



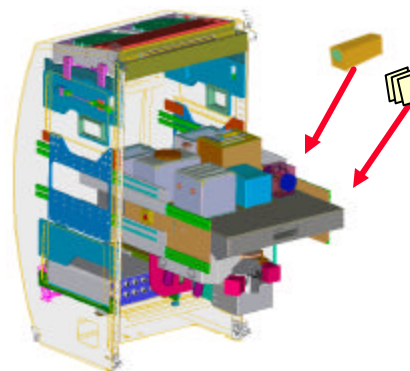
**Step 3**      **15 Minutes**  
Translate Optics Bench Forward



**Step 4**      **15 Minutes**  
Fold Down Optics Bench  
(No Tools)



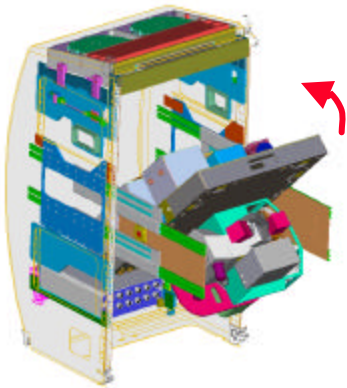
**Step 5**      **90 Minutes**  
Unstow/install PI-Specific Diagnostic/Electronics  
and Configure Facility Diagnostics



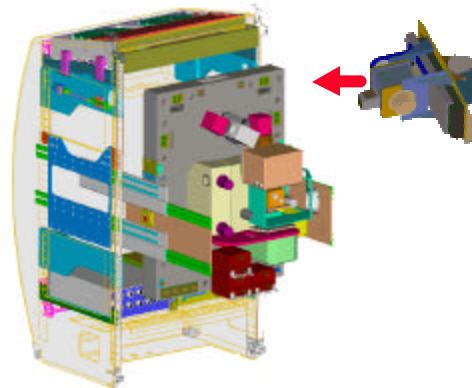
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## FCF SAR Nominal PI Set-up Scenario (2 of 2)

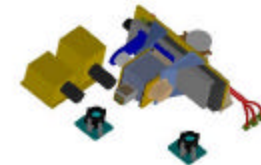
**Step 5 15 Minutes**  
Fold Up Optics Bench



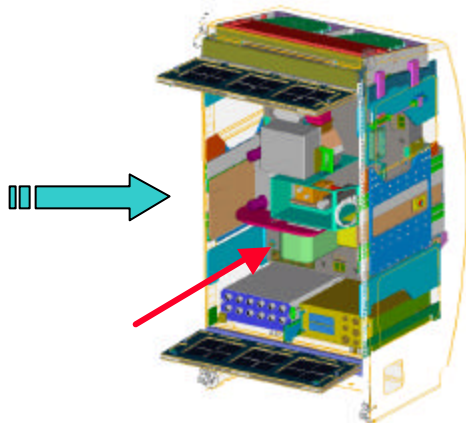
**Step 6 90 Minutes**  
Unstow/Install Experiment



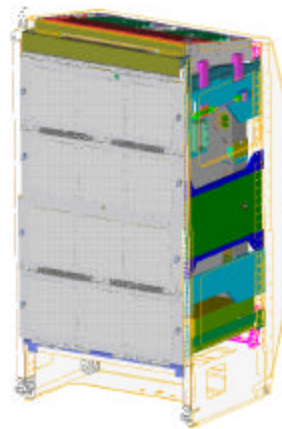
**Step 7 90 Minutes**  
Connect Interfaces and  
Rough Align Diagnostics



**Step 8 15 Minutes**  
Push Back Optics Plate and  
Engage Optics Plate Pins



**Step 9 10 Minutes**  
Close Door



**Nominal Resource Usage**  
Total Crew Time < 6.5 Hours  
Total Upmass < 60 kg

### C.3.2.2.2 SAR Shared Resources Setup Scenario

The shared resources feature of the SAR will enable the FIR and CIR to offload/enhance their diagnostic capabilities. This, in turn, will increase experiment volume and resources available to FIR and CIR science payloads.

Fiber optic communication links will be provided between SAR and FIR and SAR and CIR to enable transmission of data and command and control signals between the shared resources on the SAR and the experiments in FIR or CIR. SAR will have HRDL, MRDL, and 1533 C&C communication links with ISS and will be the primary interface with ISS.

The set-up operations for a shared resource is similar to that for a SAR experiment. An astronaut will be required to install and configure the resource package per the requirements of the particular experiment. The astronaut will first be required to fold open the FCF doors covering the un-powered SAR to gain access to the optics bench where the resource package will be installed.

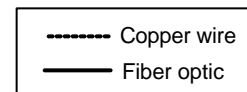
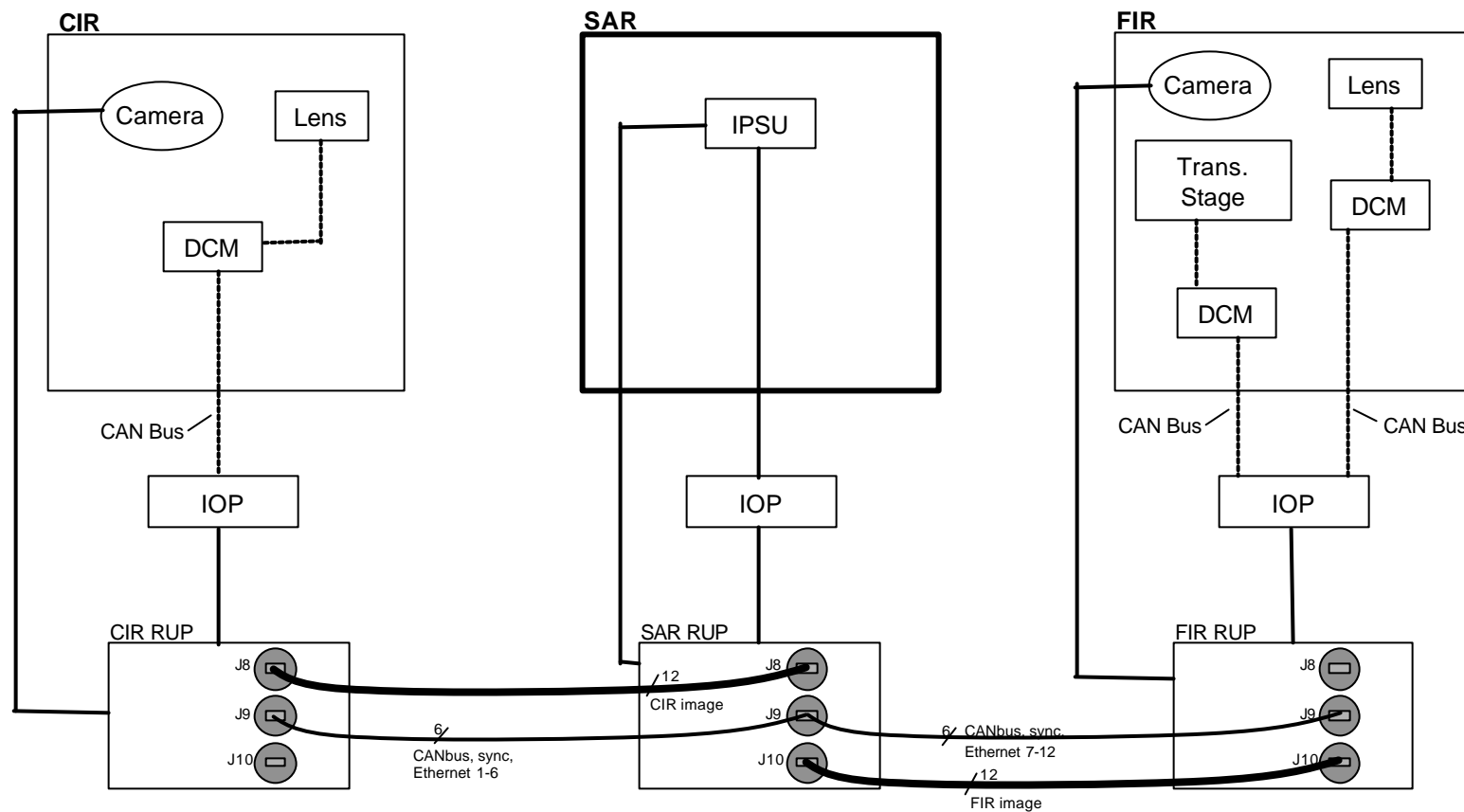
If resource package necessitates reconfiguration on the back side of the optics plate, the astronaut can gain access by retracting the pins (3 total) that secure the optics plate in its operational position. The optics plate may then be slid to its forward crew access position and locked in place. The astronaut will next activate the tilt mechanism designed to control translation of the optics plate to its extended position. The astronaut will then un-stow and install the resource package hardware. The tilt mechanism is again engaged to translate/fold the optics plate back to its upright experiment crew access position.

The astronaut will then un-stow and install the resource package hardware on the front of the optics plate. After installation and attachment of the major components to the optics plate, the astronaut will make the interface connections. The optics plate is then unlocked from its forward position and slid back to its operational position in the ISPR. The optics plate pins are engaged to lock the optics plate for operations.

The rack may be powered at this time in a minimal mode to do preliminary interface and experiment checkout (ability for powered crew interaction is limited by thermal and safety constraints). Checkout of experiment operation can now be initiated by the FIR or CIR CDMS, either from the ground or by the crew via a laptop. Finally, the astronaut closes the door.

*A typical SAR shared resources setup scenario is shown in the figure on the following page.*

## SAR Supports Science Remotely



### C.3.2.3 Operational Scenario for SAR Experiments

The Operational Scenario for SAR experiments is essentially the same as for FIR and CIR experiments. Once the SAR is powered up and operating nominally, the PI will be enabled for commanding experiment-specific equipment. The PI will then issue commands to perform an experiment run. This may be the parameters for a single test point, or a series of test points.

The PI can monitor sensor data and low resolution video to insure the experiment is operating nominally. Data for science analysis will be downlinked post-test. Based on real-time data or post-test data, the PI can adjust the test parameters for subsequent test runs. When the current operations window is over, the FCF will be shut down by the operators at the TSC.

Once SAR experiment operations commence, the SAR will operate on a daily basis. A typical ops day will be 8 to 10 hours, and will allow up to **TBD** typical experiment test points to be run depending on resource availability and PI desires. Expendables will be replenished as needed.

A typical flight day would begin with the ground operators reporting to station prior to the scheduled start of the experiment. The current on-board schedule will be reviewed and any modifications to the experiment timeline will be evaluated. All communications between the operations sites will be verified at this time. Once the PI and FCF operations team are prepared the POIC will be informed that the FCF is ready for power up.

Once power is enabled at the FCF interface the Input/Output Processor (IOP) begins its startup routine. A series of self-tests will be executed and the results will be made available to the operators. Status of the Electrical Power Conversion Unit (EPCU) will also be determined. When the startup is completed the FCF will be waiting for commands to begin experiment configuration. Health and status information will be available during the period where the FCF has power.

### C.3.2.4 Crew Interaction

Expected interaction of the crew with the flight hardware requires that the appropriate design and procedural controls are in place to prevent a hazard. Routine operations accomplished on the ground must be rigorously controlled on-orbit due to the potential effect that could result if a hazard occurs. Any color-coded markings must be accompanied by alpha-numeric notation. The SAR will be designed such that any required access to hardware during flight or ground operations can be accomplished with minimum risk to personnel.

The SAR design shall not impede emergency IVA egress to the remaining contiguous pressurized volumes. Crew egress time from experiment apparatus shall be less than 30 seconds. Local visual indicators shall not be used as the only source of safety monitoring unless the crew is actively engaged in payload operations at the visual indicator location. Payload equipment shall not be reconfigured, erected, or operated in a manner which could present a hazard to the crew, ISS/Orbiter, or which would make it unsuitable for safe return if the item is planned for return.

The need for hazard detection and safing by the flight crew to control time-critical hazards will be minimized and implemented only when an alternate means of reduction or control of hazardous conditions is not available. When implemented, these functions will be capable of being tested for proper operations during both ground and flight phases and shall use existing ISS systems for fault detection and annunciation. Likewise, payload designs should be such that real-time monitoring is not required to maintain control of hazardous functions. With PSRP approval, real-time monitoring and hazard detection and safing may be utilized to support control of hazardous functions provided that adequate crew response time is available and acceptable safing procedures are developed. Flight or ground crew hazard detection and safing actions are not available for ascent and descent flight phases.

*The SAR on-orbit flight operations concept is shown in the figure on the following page.*

## FCF SAR Flight Operations Concept

